Courtesy Douglas Aircraft Company

The Aircraft Prime Mover

AIRCRAFT ENGINE MAINTENANCE

BY

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REVISED PRINTING

With an appendix containing ten new tables

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PREFACE

Theoretically, a book on maintenance should deal strictly with maintenance, and assume that the reader is entirely familiar with the subject at hand. However, it is believed that the construction and operating principles of the aircraft engine and its accessories are not fully understood by the majority of readers for whom this book is intended. It is, therefore, necessary to devote a greater portion of this book to an explanation of the construction and operating principles of the aircraft engine than to pure maintenance. This view is further supplemented by the belief that, with a basic knowledge of construction and operating principles, the reader will find himself in an infinitely better position to cope with the individual and peculiar problems of maintenance as they present themselves.

It will behoove every mechanic to remember always that nothing mechanical has ever reached perfection and that the frailties of all mechanisms must be constantly guarded against. A thorough understanding of the working principles of the complete power plant, together with good judgment, will enable the mechanic to take cognizance of maintenance procedure and details, all of which cannot possibly be discussed in any one book.

The thoroughness, reliance, and integrity of the aircraft mechanic must never be subordinated. It is the mechanic in whom the pilot, the crew, and the passengers place their confidence and lives. If there ever was a job worthy of the saying, "If it is worth doing it is worth doing right," it is the aircraft mechanic's job. The mechanic should never fail to carry through to the most minute detail those duties with which charged, and, if ever in doubt, never hesitate to consult someone in a position to advise.

A mechanic is not a good mechanic unless he is thoroughly familiar with the use of those hand tools which he will constantly be required to use. For the aircraft mechanic these hand tools, with the exception of a very few special aircraft tools, are those with which every general mechanic should be familiar. There are many good books which deal entirely with this subject, and from which one may learn much more than it would be appropriate to incorporate in this book.

The opinions or assertions contained in this book are the private ones

of the author and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large.

The author wishes to thank the following persons and firms for the gracious cooperation which they have given in the preparation of this book: L. R. Dooley, Aero Spark Plug Co.; Alton H. DuFlon, B. G. Corp.; T. B. Whitson, James G. Biddle Co.; A. E. Bennett, Bendix Products Division, Stromberg Carburetor Division; Richard Rich, Cambridge Instrument Co.; L. E. Shedenhelm, Civil Aeronautics Administration; C. H. Winslow, Cuno Engineering Corp.; D. S. Sprague, Douglas Aircraft Co.; Carl F. Schory, Hamilton Standard Propellers; M. J. Kittler, Holley Carburetor Co.; J. Clifton Carr, Kollsman Instrument Co.; C. E. Beavan, Lord Manufacturing Co.; E. L. Eveleth, Pratt & Whitney Division of United Aircraft Corp.; Charles A. Wolf, Pioneer Instrument Division of Bendix Aviation Corp.; F. H. Clewers, Pump Engineering Service Corp.; F. Rettberg, Scintilla Magneto Division of Bendix Aviation Corp.; Dan E. Hendricks, Shell Oil Co.; Frank E. Tobin, The Texas Co.; J. S. Smith, Wright Aeronautical Corp.; C. Fayette Taylor, Massachusetts Institute of Technology; H. G. Lesley, Eastern Air Lines, Inc.

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James H. Suddeth

June, 1942

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CHAPTER I

THEORY OF OPERATION

The cycle of operation of the internal combustion engine includes the following six principal operations: (1) the admission of a charge into the cylinder, (2) the compression of the charge, (3) the ignition, (4) the combustion, (5) the expansion of the products of combustion, and (6) the exhaust of the products of combustion.

Engines are designated as 2-stroke or 4-stroke cycle (more commonly 2-cycle or 4-cycle), depending upon whether these six principal

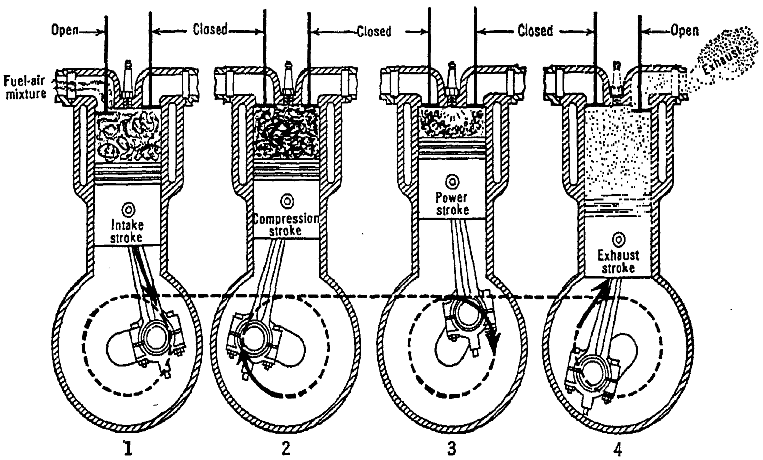


FIG. 1. Internal combustion engine, 4-stroke cycle.

operations are accomplished in two or four strokes of the piston. A stroke of the piston is its passage from top to bottom or bottom to top position. Therefore, a piston makes two strokes in one revolution of the crankshaft.

Since no 2-stroke cycle engines are manufactured in this country for aircraft use, only the 4-stroke cycle engine will be discussed. A diagrammatic sketch of the operation of the 2-stroke cycle engine is shown in Fig. 2 for comparison with the operation of the 4-stroke cycle engine shown in Fig. 1. In the 2-stroke cycle the charge must be forced into the cylinder under pressure because there is no suction stroke.

Internal combustion engines may be divided into two classifications

according to the method of mixing the fuel and the air. In one class are those engines in which the fuel and the air are mixed before entry into the cylinder. In this class belong such engines as the gasoline engine and engines using gaseous fuels. In the other class are those engines in which the fuel and the air are mixed inside the cylinder. In this class belongs the compression ignition engines using fuel oil, such as the Diesel engine. Although quite a bit of development work has been done on the aircraft Diesel engine; its adoption in this country is negligible. Hence, its operation will not be considered in this book.

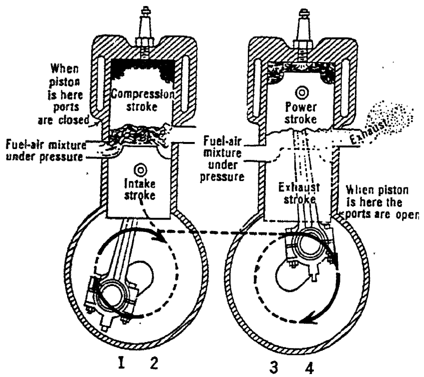


FIG. 2. Internal combustion engine, 2-stroke cycle.

The cycle of operation of the 4-stroke cycle gasoline engine can be observed in Fig. 1. During the admission stroke the piston moves down while the intake valve is held open by means of a suitable cam mechanism. A charge of fuel and air mixture is drawn into the cylinder by the suction created as the piston moves downward or, more precisely, the mixture is forced into the cylinder by the outside pressure as the pressure within the cylinder decreases. The cam mechanism is so designed that as soon as the charge has entered the cylinder the intake valve is closed by the force of a valve spring. The admission stroke is now completed. During this stroke, the exhaust valve is closed.

The piston moves upward on the second or compression stroke. Both intake and exhaust valves are closed. The charge of fuel and air mixture in the cylinder is compressed. As the piston nears the top of the stroke an electric spark is created by an electric current jumping between the terminals of a spark plug. The spark ignites the charge and combustion takes place.

After the charge is ignited the heat of combustion causes a very rapid rise in pressure which forces the piston down on its third stroke. This third stroke is variously called the expansion, firing, or power stroke. During this stroke the inlet and exhaust valves are both closed.

As the piston nears the bottom of the expansion stroke the valve cam mechanism opens the exhaust valve. When the piston moves

upward on its fourth stroke the burnt mixture (products of combustion) is forced from the cylinder. This is the exhaust stroke. During this stroke the inlet valve is closed. The cycle is now complete and may be repeated over and over.

The fundamental principle of operation of the 4-stroke cycle gasoline engine as just discussed is very simple, but there are several things concerning the actual operation which must be considered. To understand thoroughly the problems encountered in the actual operation, it will be necessary to consider the various phenomena and changes which occur in the cylinder of the internal combustion engine.

The internal combustion engine is one form of heat engine. In any heat engine the energy which is released by the combustion of fuel is transformed into work. The steam engine is a form of external combustion heat engine. Here the energy of the fuel is changed to heat energy in the furnace and this heat energy is transferred to water in the boiler. The water is changed to steam and the heat energy in the steam is then converted into mechanical work in the steam turbine or reciprocating engine. In the internal combustion engine the combustion of the fuel takes place within the cylinder of the engine itself.

Since we shall be concerned with relations of heat and mechanical work and the behavior of the working substance, it is desirable to review the underlying laws of physics.

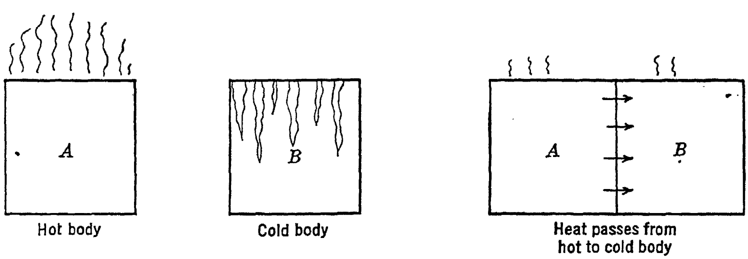


FIG. 3. Transfer of heat from one body to another as a result of difference in temperatures between the bodies.

Heat is a form of energy which will transfer from one body to another, when the two are brought into contact with each other, by virtue of the temperature difference between them.

The mean *British thermal unit* (Btu) is the unit used for expressing quantities of heat. It is defined as the amount of heat required to raise the temperature of 1 lb of water 1°F at standard temperature (68°F) and a constant pressure of 29.92 in. of mercury (14.7 lb per sq in.).

Temperature is a unit used for measuring the intensity of heat. It must not be confused with the unit for expressing the quantity of heat. The degree Fahrenheit (°F) is one of the units used for expressing temperature. On the Fahrenheit scale 32°F is the temperature at

FIG. 4. Increase in temperature of one pound of water caused by the addition of one Btu (heat).

which water freezes and 212°F is the temperature at which water boils under a constant pressure of 1 atm.

Another temperature scale which will be used is called the Rankine scale. The magnitude of the degree Rankine (°R) is equivalent to a degree Fahrenheit, but on the Rankine scale the freezing point of

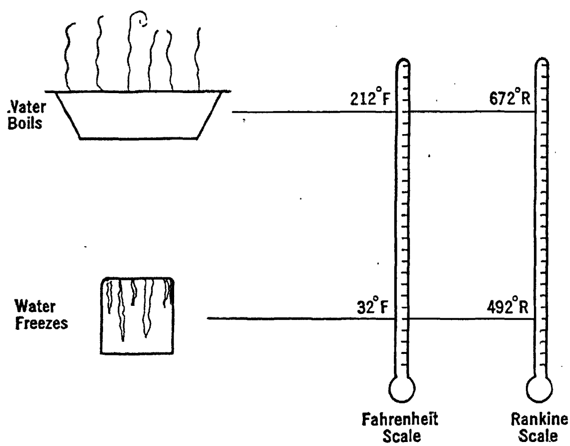


FIG. 5. Comparison of Fahrenheit and Rankine temperature scales.

water is 492°R and the boiling point of water is 672°R under a constant pressure of 1 atm. Equivalent actual temperatures on the Rankine scale are 460 degrees higher than those on the Fahrenheit scale. The Rankine scale is referred to as an absolute temperature scale. The need for such a scale will be appreciated when the laws of Charles are considered.

An *atmosphere* is a pressure of approximately 14.7 lb per sq in. and is equivalent to the pressure required to support a column of mercury

(Hg) 29.92 in. high. This is the standard atmospheric pressure at sea level.

Absolute pressure is the pressure indicated by a gauge whose zero mark is established at the point which the hand indicates while the gauge line is subjected to a complete vacuum. This will make the absolute pressure gauge read 14.7 lb per sq in. at standard sea level atmospheric conditions.

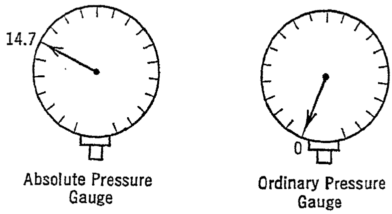


FIG. 6. Comparison of gauge readings on absolute and ordinary pressure gauges when both are subjected to pressure of 1 atm.

The unit of work is the *foot-pound* (ft-lb). It is the work done by a force of 1 lb acting through a distance of 1 ft. All forms of work can be resolved into lifting a weight through a certain distance.

The rate of doing work is known as *horsepower*. It is defined as 33,000 ft-lb of mechanical work per minute. Note that horsepower is a rate and not a quantity and must, therefore, always be associated with time to give a relation to quantity of mechanical work.

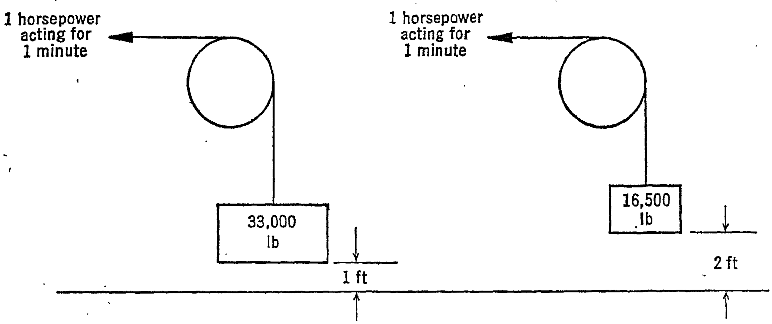


FIG. 7. One horsepower is equal to 33,000 ft-lb of work per minute.

Since energy is the power to do work and heat is one form of energy, it follows that heat is convertible into mechanical work. Therefore, there must be a relation between the units of heat and the units of work. The relation now accepted as correct is that 1 Btu of heat is equivalent to 778 ft-lb of work. This quantity is known as the *mechanical equivalent of heat.*

Laws of Perfect Gases. There are two principal laws which govern the expansion and compression of gases. These laws are known as Boyle's law and Charles' law. They are true for a perfect gas, but

there is no such thing as a perfect gas. However, there are gases which conform very closely to these laws. The gases which, under ordinary temperatures and pressures, conform closely to these laws are known as permanent gases. Air, a mixture of several gases, may be considered a permanent gas; therefore, it closely adheres to these laws over moderate ranges of temperature and pressure. Over wide ranges of temperature and pressure considerable error may be expected if air is considered as a perfect gas. However, to simplify the discussion air will be considered as a permanent or perfect gas.

The temperatures and pressures referred to in the following laws are absolute.

Boyle's law states that for a given mass of gas, at constant temperature, the pressure varies inversely as the volume.

It may be expressed in an equation as

$$P_1V_1 = P_2V_2 = \text{a constant} \qquad [1]$$

where P and V represent pressure and volume respectively, and the subscripts 1 and 2 represent, respectively, initial and final conditions of pressure and volume.

From the above equation we derive the following expressions:

$$\frac{\text{Initial volume} \times \text{Initial pressure (abs)}}{\text{Final volume}} = \text{Final pressure (abs)} \qquad [2]$$

$$\frac{\text{Initial volume} \times \text{Initial pressure (abs)}}{\text{Final pressure (abs)}} = \text{Final volume} \qquad [3]$$

Any unit, such as cubic inches or cubic feet, may be used to express the volume as long as the same unit is used consistently.

From the above we can see that, if we take a certain mass of air and reduce its volume by half, the absolute pressure will be doubled. Let us take 1 cu ft of air in a cylinder which has a piston at one end and a pressure gauge and thermometer for reading the absolute pressure and absolute temperature of the air in the cylinder (Fig. 8). The absolute temperature is 528°R and the absolute pressure is 14.7 lb per sq in. Now, if the piston is pushed into the cylinder until this volume is reduced by half, we will find that the pressure has increased. As the piston is pushed in, though, we will have to cool the cylinder to keep the temperature constant. Why cooling is necessary in this case to maintain a constant temperature will be seen from the law of Charles which follows. With the volume reduced to half and the absolute tem-

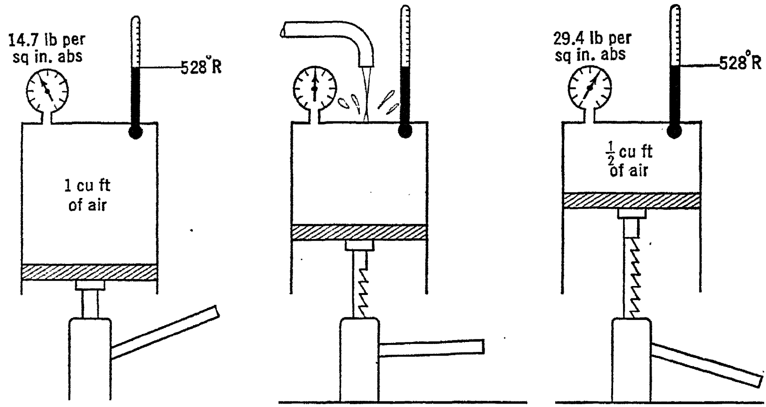


FIG. 8. Gas under constant temperature with changing volume and pressure.

perature still 528°R, the absolute pressure will now be twice what it was originally, or 29.4 lb per sq in. abs.

$$\frac{\text{Initial volume} \times \text{Initial pressure (abs)}}{\text{Final volume}} = \text{Final pressure (abs)} \quad [2]$$

$$\frac{1 \times 14.7}{\frac{1}{2}} = 29.4 \text{ lb per sq in. (abs)} \quad [\text{Final pressure (abs)}] \quad [2]$$

Charles' law states: (*a*) if the volume of a given mass of gas is kept constant, equal increments of pressure accompany equal increments of temperature; (*b*) if the pressure of a given mass of gas is kept constant, equal increments of volume accompany equal increments of temperature.

As equations Charles' law may be written:

(*a*) $$\frac{P_1}{P_2} = \frac{T_1}{T_2} \quad \text{when volume is constant} \quad [4]$$

(*b*) $$\frac{V_1}{V_2} = \frac{T_1}{T_2} \quad \text{when pressure is constant} \quad [5]$$

where P, T, and V represent absolute pressure, absolute temperature, and volume respectively. The subscript 1 designates the initial state and the subscript 2 designates the final state of the gas.

The first part of Charles' law means that if a certain mass of air is confined in a closed vessel (so the volume cannot increase) and if heat is applied to this mass of air, the pressure will increase in proportion to the rise in temperature of the air. Conversely, if the tem-

perature of the mass of air is lowered, the pressure will decrease in proportion to the decrease in temperature. Take, for instance, 1 lb of air confined in a closed cylinder at 14.7 lb per sq in. absolute pressure and a temperature of 528°R (Fig. 9). If we apply heat, the volume must remain the same since the cylinder confines the air. The temperature rises and at the same time the pressure rises. If we raise the temperature to 1056°R, or double what it was originally, then we will obtain an increase of pressure to 29.4 lb per sq in. abs, which is double the original pressure.

The second part of Charles' law means that if a certain mass of air is confined in a vessel in such a manner that a constant pressure may

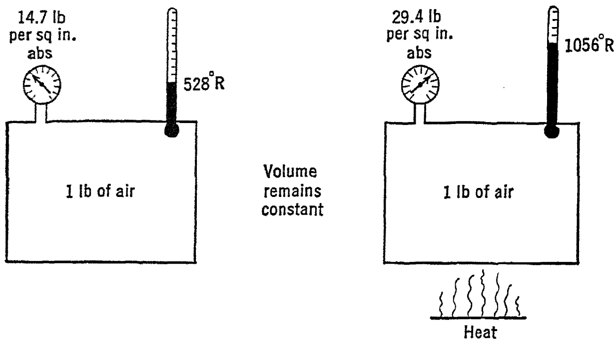


FIG. 9. Gas under constant volume with changing temperature and pressure.

be maintained, then any rise in temperature will cause a proportional increase in volume. Conversely, any drop in temperature will cause a proportional decrease in volume. Let us take a mass of air contained in a cylinder with a piston at the top weighted down so as to maintain a constant pressure of, say, 20 lb per sq in. abs (Fig. 10). The initial volume, we will say, is 1 cu ft and the initial temperature is 528°R. If, now, the temperature is increased to 1056°R, or double the initial temperature, the volume will increase to 2 cu ft, or double the initial volume. The pressure, of course, remains 20 lb per sq in. abs.

If equal volumes of several different gases at 32°F are kept at a constant pressure, not necessarily the same pressure for all, and heated through 1°F, they will increase in volume in each case by 1/492 of the initial volume. Hence, if the initial volume of any gas at 32°F is 492 cu in., it will be 493 cu in. at 33°F, 494 cu in. at 34°F, etc. Conversely, if the temperature is reduced, the initial volume will contract by 1/492 of itself for each degree of temperature below 32°F. Therefore, at 0°F the volume will be $492 - 32 = 460$ cu in., and at 460°

below 0°F, the volume will be 0. In other words, if a perfect gas should be cooled to a temperature of −460°F it will have neither volume nor pressure and will, therefore, establish an ideal zero point from which all temperature may be counted. This zero point is called the absolute zero of temperature. It is the zero point on the Rankine scale.

The laws of Boyle and Charles can be combined to give the following general characteristic equation for a gas:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \tag{6}$$

Specific Heat. The specific heat of a substance is the ratio of the heat required to raise the temperature of a unit weight of the sub-

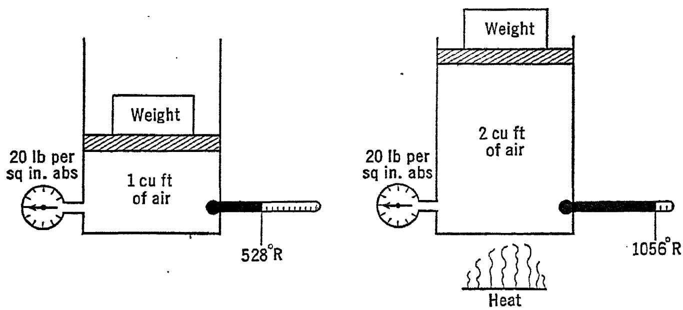


FIG. 10. Gas under constant pressure with changing temperature and volume.

stance 1° to the heat required to raise the same unit weight of water 1° at some specified standard temperature. At the specified standard temperature (68°F), 1 Btu is required to raise the temperature of 1 lb of water 1°F. Thus, the specific heat of a substance is numerically equal to the quantity of Btu's necessary to raise the temperature of 1 lb of the substance 1°F. The specific heat of a particular substance varies with the temperature and pressure.

There are two principal conditions under which a mass of gas may be heated. It may be confined within a definite space and thereby heated at a constant volume, or it may be confined under a definite pressure and allowed to expand at this constant pressure as it is heated. When a gas is confined at a constant volume and heated, the increase in pressure resulting from the addition of heat does not, of course, perform work (Fig. 9). When, however, the gas is confined at constant pressure and allowed to expand as it is heated, work is per-

formed. The amount of heat required to raise 1 lb of gas 1°F in temperature differs under these two circumstances. The amount of heat required is greater when the gas is heated at constant pressure than when it is heated at constant volume. The excess of heat required in the former instance is equal to the amount of work done by the gas in expanding at constant pressure. It can be seen from Fig. 10 that the work done in expanding a gas at constant pressure is equal to the product of the weight required to maintain the constant pressure and the distance it is raised.

If a gas expands or is compressed and during the process heat is neither received by nor emitted from the gas by conduction, convection, or radiation, the process is known as an *adiabatic* (isentropic) process. If the gas expands adiabatically its internal energy is decreased by an amount exactly equal to the amount of external work done during expansion. If it is compressed it gains an amount of internal energy exactly equal to the work of compression done upon it.

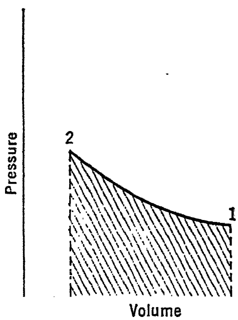


FIG. 11. Work is represented by shaded area.

Work. When a force acts through a distance mechanical work is done. This work is the product of the force and the distance through which the force acts. When a pressure P, which is a unit force, acts on a piston of area A, then the total force is the product of the unit pressure and the area, or $P \times A$. If the length of the stroke is L, then the work is equal to $P \times A \times L$. However, A times L is equal to the volume V displaced, and thus the product of P and V represents work. Of course, a proper conversion constant must be used to express P times V in foot-pounds of work.

If a curve representing a process is plotted on a pressure-volume diagram, the area beneath the curve and between the limiting ordinates is equivalent to the work done, as the area is a product of P and V. In Fig. 11 the work required to compress a gas from volume and pressure of point 1 to a smaller volume and higher pressure of point 2 is represented by the shaded area. If the gas expands from point 2 to point 1 it will do the work represented by the shaded area. In a cycle the net area enclosed by the cycle on the pressure-volume diagram represents the network of the cycle.

In Fig. 12 the work done in compressing a gas from point 1 to point 2 is less than the work which is performed by the same gas when

it expands from the higher pressure at point 3 to the pressure and volume represented by point 4. The net difference in the work done on the gas in compressing it and the work done by the gas in expanding is the net difference in the areas under the curves, which is represented by the shaded area. Hence, the area enclosed by a cycle represents the work of the cycle.

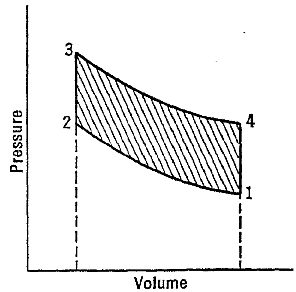


FIG. 12. Work of complete cycle is represented by the enclosed area of the cycle which is shown shaded.

Ideal Cycle. In order that the actual working of one engine may be compared with the actual working of other engines, it is necessary to have some ideal standard of comparison. The Otto, or constant-volume cycle, is usually used as an ideal to which the 4-stroke cycle gasoline engine is compared. It is closely followed by the actual cycle of the gasoline engine.

In the Otto cycle it is assumed that the working substance is a "perfect gas"; that the specific heat of the gas is constant; that there are no heat losses in the engine; that the compression and expansion are adiabatic, and that any chemical changes during combustion are disregarded. The conditions of the Otto cycle are not

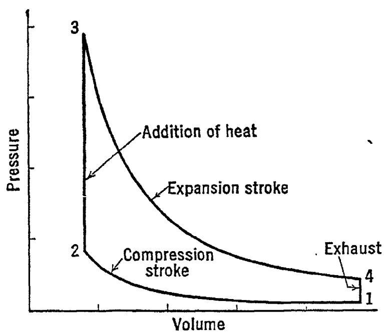


FIG. 13. Pressure-volume diagram of the Otto cycle.

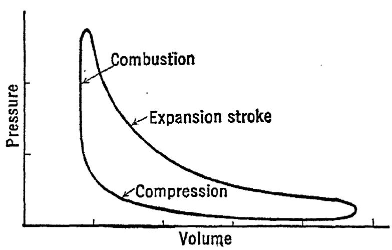


FIG. 14. Pressure-volume diagram of the actual cycle.

possible in the actual cycle, but they represent an ideal limit which the actual may approach. A pressure-volume diagram of both the Otto and actual cycle are shown in Figs. 13 and 14. The cycle of working changes in the Otto cycle is as follows:

1. The piston is at the bottom of the stroke. The volume and pressure of the gas in the cylinder are represented by point 1 in Fig. 13. The piston is moved to the top of the stroke, thereby compressing the gas. The volume is decreased and the pressure is increased as indicated by point 2. The compression was adiabatic (heat was neither added to nor released from the gas by convection, conduction, or radiation). This does not mean, however, that the temperature of the gas did not increase with increased pressure.

2. As long as the piston remains at the top of the stroke the volume remains constant. If, now, at a constant volume, heat is added to the gas, the pressure will increase to point 3.

3. The piston now starts on its down stroke and the gas expands adiabatically along the curve 3–4 to point 4. At point 4 the piston is at the bottom of the stroke. The gas does not lose any heat by convection, conduction, or radiation during the expansion stroke, but it does lose heat equivalent to the work which it performs in pushing the piston down.

4. At point 4 the exhaust valve is opened and the gas is rejected at constant volume from point 4 to point 1, with falling pressure and temperature.

In the actual cycle the compression is not adiabatic since the fuel-air mixture receives heat from the piston and cylinder walls. Heat is not added at a constant volume, as ignition occurs before the piston reaches the top of the stroke and combustion continues until the piston is partially down on the expansion stroke. The expansion stroke is not adiabatic as part of the heat is given up to the cylinder walls and piston. The exhaust valve opens slightly before the piston reaches the bottom of the stroke and stays open through the exhaust stroke and, therefore, the heat is not rejected at constant volume.

Compression Ratio and Thermal Efficiency. The ratio of the volume at point 1 to the volume at point 2 (Fig. 13) is known as the *compression ratio*. In other words, it is the ratio of the volume in the cylinder when the piston is at the bottom of the stroke to the volume in the cylinder when the piston is at the top of the stroke.

Energy was added to the gas by the work expended in compressing it. This energy was reconverted to work as the gas expanded and pushed the piston downward. Therefore, we need not consider this conversion from work to energy and back to work in computing the efficiency of the cycle. The energy which must be considered is the heat which is added from point 2 to point 3 and that which is rejected from point 4 to point 1. If an engine could convert all the heat supplied to it into mechanical work its thermal efficiency would be 100

per cent. The thermal efficiency of any heat engine may be expressed as:

$$\text{Thermal efficiency} = \frac{\text{Heat received} - \text{Heat rejected}}{\text{Heat received}} \qquad [7]$$

Hence, the thermal efficiency of the Otto cycle may be written:

$$\text{Thermal efficiency} \quad \frac{\text{Heat received (2 to 3)} - \text{Heat rejected (4 to 1)}}{\text{Heat received (2 to 3)}}$$

From equation 7 it is obvious that the thermal efficiency can be increased only if the heat received is increased or the heat rejected is decreased, or by the combined increase of the former and decrease of the latter.

It can be shown that the ratio of the heat received to the heat rejected is dependent upon the volume at the beginning and end of the compression stroke. Since the volume at the beginning and end of the compression stroke determines the compression ratio, then it follows that the thermal efficiency is dependent upon the compression ratio, the efficiency increasing with an increase in compression ratio. The increase in thermal efficiency with increase in compression ratio is illustrated by the curve of Fig. 15.

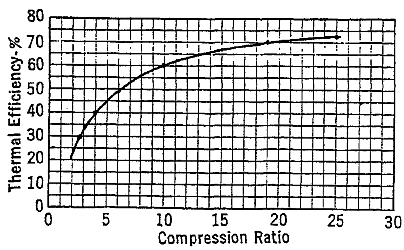


FIG. 15. Thermal efficiency vs. compression ratio — Otto cycle.

In the gasoline engine a combustible mixture is compressed, hence the compression ratios that can be used in such an engine are limited by the spontaneous ignition temperature of the mixture. Another limiting factor encountered as the compression ratio increases is detonation (knocking) which is very detrimental to the engine.

The *indicated thermal efficiency* is the ratio of indicated work performed by the engine to the heat received.

Indicated thermal efficiency =

$$\frac{\text{Indicated horsepower converted to Btu per hour}}{\text{(Pounds fuel per hour)} \times \text{(Btu per pound of fuel)}} \qquad [8]$$

The *relative thermal efficiency* is the ratio of the indicated thermal efficiency to the ideal thermal efficiency. It shows how close the actual

engine comes to the ideal engine in performance. Some of the modern engines attain relative thermal efficiencies above 85 per cent.

Piston Displacement and Volumetric Efficiency. Heat added during the actual cycle from point 2 to point 3 (Figs. 13 and 14) is supplied by the combustion of the fuel and air mixture. The power developed by an engine largely depends upon the amount of heat added. Hence, the greater the mass of fuel-air mixture added, the greater will be the power developed.

When the piston moves from the bottom of the stroke to the top of the stroke a specific volume is displaced. This volume displaced by the piston is known as *piston displacement,* and is usually expressed in cubic inches. It is the product of the area of the cylinder bore and the length of the piston stroke. In a multiple cylinder engine, this product is multiplied by the number of cylinders to give the total displacement of the engine.

Volumetric efficiency is expressed in terms of percentages. It is the relation of the volume of fuel-air mixture admitted into the engine cylinders compared to the total piston displacement of the engine. It may be expressed as follows:

$$\text{Volumetric efficiency} = \frac{\text{Volume of charge}}{\text{Piston displacement}} \tag{9}$$

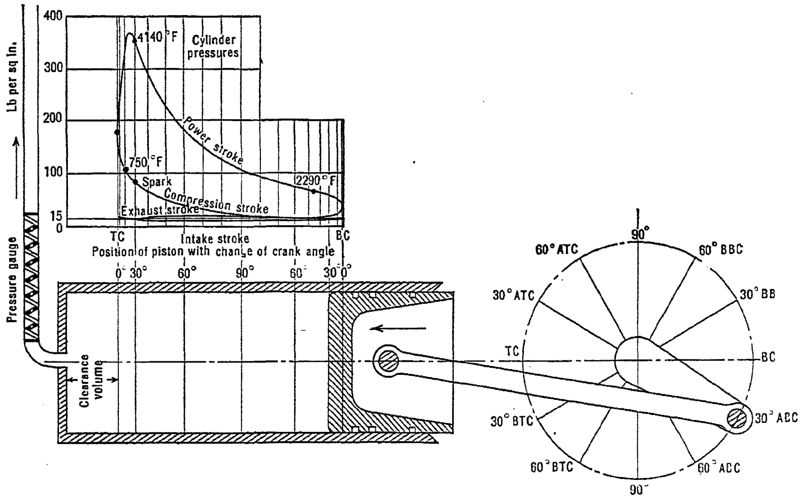
It will, of course, be realized that a given mass (weight) of fuel-air mixture will occupy different volumes under different conditions of pressure and temperature. Therefore, in computing volumetric efficiency a comparison must be made with the volume which the mass of fuel-air charge would occupy under particular conditions, such as standard atmospheric pressure and temperature.

Since, as previously stated, the horsepower output of an engine increases with the mass of fuel-air mixture taken into the cylinders, it follows that horsepower output will increase with the volumetric efficiency. A supercharger, discussed on page 19, greatly increases the volumetric efficiency of an engine.

Mean Effective Pressure. Mean effective pressure (mep) is the average pressure which, acting the full length of the stroke, will do the same amount of work as the actual changing pressure within the cylinder does in forcing the piston downward.

Indicated Horsepower. The work done by the expanding gaseous mixture in pushing the piston down is known as the indicated work. The rate at which this work is done is known as the indicated horsepower. The total mean force exerted by the gas pressure on the piston is a product of the area of the piston and the mean pressure per unit

area, or $P \times A$. The force exerted upon the piston and the distance the force acts (length of stroke) being known, the work done per stroke may be determined. The work per power stroke and the number of



Courtesy Civil Aeronautics Administration

FIG. 16. Typical pressure-volume indicator card diagram.

strokes per unit of time being known, it is simple to determine the indicated horsepower (ihp).

$$\text{Ihp} = \frac{\text{Work per power stroke} \times \text{Number of power strokes per minute}}{33{,}000}$$

$$\text{Ihp} = \frac{P \times A \times L \times \frac{\text{Rpm}}{2}}{33{,}000} \qquad [10]$$

where: P = mean effective pressure in pounds per square inch,
A = area of cylinder bore in square inches,
L = length of stroke in feet.

The rpm is divided by 2 since there is only 1 power stroke for every 2 revolutions of the crankshaft in a 4-stroke cycle engine. Formula 10 is for a single cylinder engine. To obtain the total ihp of an engine it is necessary to multiply by the total number of cylinders.

Brake Horsepower. Brake horsepower (bhp) is the actual horsepower delivered at the engine output shaft. If it were not for mechanical losses, such as pumping and frictional losses, the ihp would be available at the output shaft and would, therefore, be the same as the

bhp. However, these losses are present and their magnitude determines the *mechanical efficiency* of the engine.

$$\text{Mechanical efficiency} = \frac{\text{Brake horsepower}}{\text{Indicated horsepower}}$$

Mechanical efficiency varies with the load, and in modern engines, may be as high as 96 per cent at rated load.

The *brake thermal efficiency* of an engine, also called the overall efficiency, is the ratio of the heat received by the engine to the heat equivalent of the shaft work output of the engine. It may be written:

Brake thermal efficiency =

$$\frac{\text{Bhp converted to Btu per hour}}{(\text{Pounds fuel per hour}) \times (\text{Btu per pound of fuel})} \qquad [12]$$

CHAPTER II

FACTORS OF OPERATION

Regulation of Power. There are only a few methods which are practical for regulating the power of an aircraft engine; however, there are a number of methods by which it might be done. By understanding the various methods by which power may be regulated, a better cognizance may be had of the various troubles which may cause an engine to lose power.

Qualitative regulation is the variation of the proportion of air and fuel in the charge. This variation can only occur within certain limits, since a mixture of too little fuel or too much fuel is not combustible. This type of regulation may be accomplished by varying the fuel supply while maintaining a constant air supply. It can also be accomplished by delaying the closing of the exhaust valve so that some of the exhaust gases return to the cylinder to dilute the incoming fuel-air mixture.

Quantitative regulation is the variation (throttling) of the quantity of the fuel-air mixture without changing the ratio of the fuel to the air. This variation of the mass of the charge may be done by throttling the charge throughout the whole of the suction stroke or by varying the instant of closing of the inlet valve. The former method is employed in aircraft engines. The latter method of cut-off regulation would require a complex valve gear mechanism.

The *hit-and-miss* system of regulation omits the fuel-air charge entirely, or its ignition, so that no working stroke occurs until the speed falls to a determined normal speed. There are several methods by which an engine can be made to miss the working stroke:

1. Keep the fuel valve closed, so that only air enters during the suction stroke.
2. Omit the ignition of the charge.
3. Keep the inlet valve closed during the suction stroke.

Regulation by *varying the time of ignition* is a method which can very easily be adopted mechanically. All aircraft engines use some electrical method of ignition. The ignition can very readily be arranged so as to be capable of advancement or retardation, either independently or in connection with the throttle movement.

When the ignition is retarded the combustion does not produce the maximum possible pressure within the cylinder.

A considerable amount of power and fuel is wasted by using the variation of the time of ignition as the only method of regulating the speed and power. Another disadvantage of this system of regulation is that the length of the stroke may not be sufficient for the complete combustion of the fuel-air mixture before the exhaust valve opens. The combustion will continue into the exhaust passage, causing objectionable heating of the cylinder and exhaust passage.

Regulation may be effected by a *combination of throttling and variation of the time of ignition.* This system is sometimes used in aircraft engines and is the general practice in automobile engines. As the speed of an engine changes, the time of ignition for the most efficient power changes. The greater the piston speed the more the spark should be advanced. Where changes of speed as well as power are made, this system is very desirable. The spark and throttle levers are usually moved with a definite relation to each other. The greatest economy of fuel will result when the engine is driven with the greatest spark advance the engine will allow and as little throttle opening as is necessary to give the power needed.

Air Consumption. With the ignition time adjusted for optimum results and other things remaining constant, the indicated horsepower of an engine varies directly with its air consumption.

The mass, or weight, of air taken into the engine is dependent upon its volumetric efficiency. It is necessary when computing volumetric efficiency to make a comparison with some standard conditions, such as standard sea level atmospheric conditions. The necessity for this may be seen from the following discussion: Suppose that a certain mass of fuel-air mixture at standard sea level atmospheric pressure and temperature is drawn into a cylinder. This mass of fuel-air mixture has a definite volume at standard sea level atmospheric conditions. If its pressure and temperature are not changed as it is drawn into the cylinder, its volume, which we will say is equal to the displacement of the piston, will not change, and the volumetric efficiency will be 100 per cent, if sufficient time is allowed for all the air to pass into the cylinder. Now, suppose that, before this mass of fuel-air mixture is drawn into the cylinder, its temperature is increased. The increase in temperature will cause the volume of the mass to increase. The cylinder will draw in only a certain volume of mixture, and since the volume of the mass has increased, then part of this particular mass will not be admitted. To determine the volumetric efficiency in this instance, it will be necessary to reduce to standard atmospheric temperature that portion of the mass taken into the cylinder; measure its volume at atmospheric temperature and pressure, and then compare this volume with the piston displacement.

A similar increase in the volume of a unit mass of mixture would occur if the pressure were lowered. It is therefore evident that volumetric efficiency is dependent upon the inlet temperature and pressure of the incoming charge. Several other factors affect volumetric efficiency, the most important being: restriction of the intake system and valves to the flow of the charge; temperatures and pressures encountered in the intake system; temperature and pressure of the residual gases in the combustion chamber, and the time of opening and closing of the valves.

It is desirable to keep the velocity throughout the intake system as low as possible since the resistance offered to the flow of the charge is proportional to the square of the velocity. If the diameters of the intake valves and passages are large, the velocity of the incoming charge does not increase so rapidly with increased air consumption.

Valve timing, which has considerable effect upon volumetric efficiency, will be discussed in the next chapter.

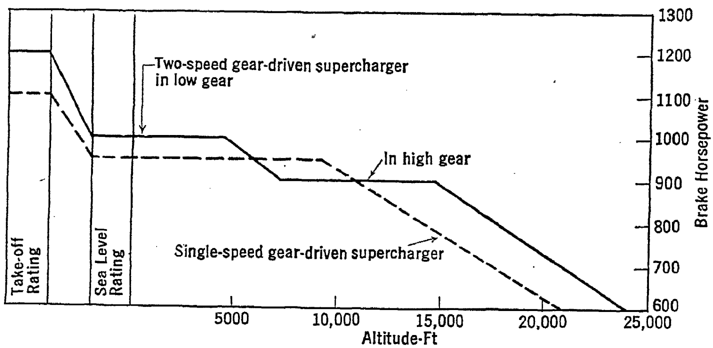


FIG. 17. Typical power vs. altitude curves of supercharged engines.

Supercharging. At an altitude of 20,000 ft the atmospheric pressure is one-half, and at 35,000 ft it is one-quarter of the normal sea level value. At these reduced pressures a cubic foot of air will weigh considerably less than a cubic foot of air at sea level. This reduction in weight per unit volume of air, with increase in altitude, reduces the volumetric efficiency and hence the power output of an engine. The reduction in volumetric efficiency can be offset by increasing, through the use of a supercharger, the pressure of the air before it goes to the cylinders.

A supercharger is simply an air pump; it requires a certain amount of power from the engine for its operation. Superchargers are designed to provide a pressure at the cylinder inlet ports which will provide the

cylinders with sufficient air capacity to allow the engine to develop its rated power with the throttle valve wide open at some particular altitude. The altitude at which the engine develops rated power with the throttle wide open is known as the *rated altitude.* Below this altitude it is necessary to close the throttle partially to prevent the engine from developing more than rated power. Above this rated altitude the power commences to decrease with increase in altitude, because the supercharger cannot maintain the required pressure.

Some Factors Affecting Output. As previously stated, the work of a cycle is represented by the area enclosed by the cycle on a pressure-volume diagram. With the proper instruments a pressure-volume diagram of the actual cycle within the cylinder may be obtained. These pressure-volume diagrams are called *indicator cards,* since they indicate the actual pressures and volumes within the cylinder during the cycle.

An ideal actual cycle is shown in Fig. 18. The pressure scale is given only for comparative purposes. The indicated positive work is represented by the area enclosed by the upper portion of the cycle. The lower shaded area of the cycle is negative work. The negative work is that work consumed in the suction of the fuel-air mixture into the cylinder and the exhaust of the products of combustion. The negative work must be deducted from the positive work to obtain the net indicated work.

If the ignition is retarded, the combustion line, which is shown as a partially vertical line on the ideal card, becomes inclined to the right as shown in Fig. 19. The more the spark is retarded the more the line will be inclined. The enclosed area of the cycle is reduced; this indicates a reduction in the work.

If the ignition is too early the combustion line will be inclined to the left (Fig. 20). The pressure reaches its maximum before the completion of the compression stroke, thus causing a loop at the top of the cycle. The area of this loop represents negative work, which must be subtracted from the positive work of the rest of the cycle. A continued advance of the ignition time will increase the negative work until it surpasses the positive work, causing the engine to stop.

Fig. 21 shows the reduction of work caused by the loss of compression, other conditions remaining unchanged. The inclination of the combustion line and the lower final pressure (Fig. 22) caused by the lean mixture are due to the slower rate of combustion and smaller amount of heat liberated by combustion of the lean mixture.

Small exhaust valves, restricted exhaust passage, or improper timing of the exhaust valves will create a high back pressure in the cylinder.

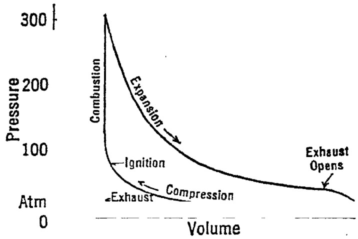


FIG. 18. The ideal operating pressure-volume diagram.

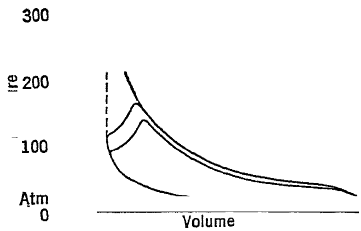


FIG. 19. The effect of retarded ignition.

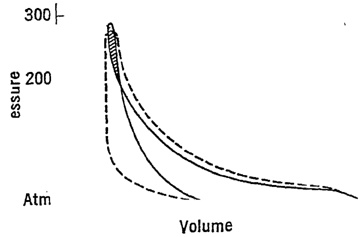


FIG. 20. The effect of too early ignition.

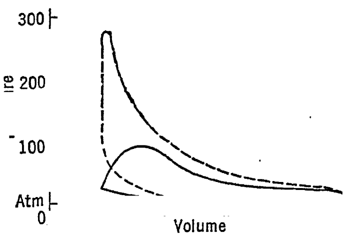


FIG. 21. The effect of loss of compression.

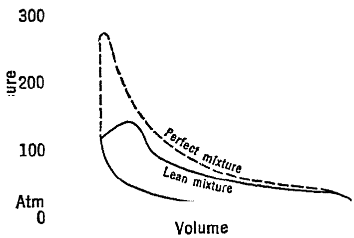


FIG. 22. The effect of a lean mixture.

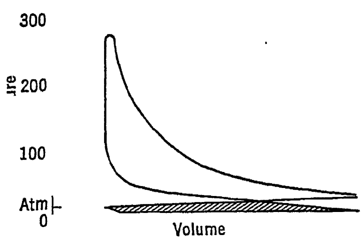


FIG. 23. The effect of high exhaust back pressure.

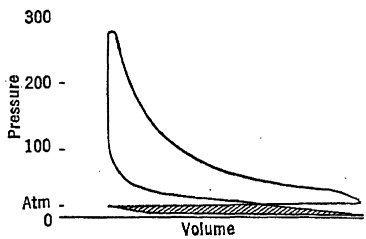


FIG. 24. The effect of faulty admission.

This high back pressure will require extra work to force the products of combustion from the cylinder. The extra negative work is shown by an increase in the area of the shaded section (Fig. 23).

Restricted admission of the fuel-air mixture causes a low pressure to be created in the cylinder. This produces a large loop below the atmospheric pressure line (Fig. 24), which increases the negative work. The loss of power which would also be caused by the loss in volumetric efficiency in this case is not shown.

Flame Propagation. The heat which is converted into work through the raising of pressure within the cylinder of an internal combustion engine is obtained from the combustion of the fuel-air charge. The fuel-air charge is usually supplied to the cylinder in a fairly homogeneous mixture by a carburetor-induction system. The time required for combustion is short, but relatively, when compared with piston speed, the time of combustion may be considered as appreciable.

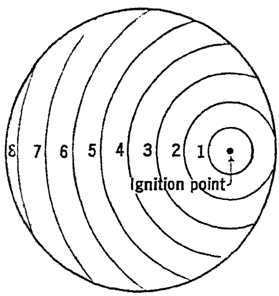


FIG. 25. Flame travel within the combustion chamber.

The combustion of the charge within the cylinder begins at the spark plug and spreads to the rest of the mixture. There is a flame front as the combustion progresses. The lines 1, 2, 3, etc., of Fig. 25 represent the flame fronts as the flame progresses to the rest of the mixture.

Because of the time required for the combustion, ignition should occur before the piston reaches top dead center (T.D.C.). Combustion continues past top dead center; this means that the pressure at the beginning of the power stroke is not as high as it would be if combustion were completed at top dead center. The above condition reduces the efficiency as compared with the ideal Otto cycle. In the Otto cycle it was assumed that all heat was added while the piston was at top dead center.

The rate of combustion of the fuel-air mixture within the cylinder depends upon the following factors:

1. *Pressure.* The speed of combustion increases with an increase in pressure.

2. *Temperature.* The speed of combustion decreases with increase in intake temperature. Oddly, the speed of combustion of motionless mixtures increases with the temperature, but the reverse action occurs in turbulent mixtures.

3. *Compression Ratio.* As the compression ratio is increased there

is an increase in both the pressure and temperature of the compressed charge. The increased pressure tends to increase the speed of combustion whereas the increase in temperature tends to slow down the combustion. The effect of the pressure increase is predominant, since actual tests show that the speed of combustion increases with an increase in compression ratio.

4. *Fuel-Air Ratio.* A lean mixture burns faster than a rich mixture. A mixture close to best power fuel-air ratio burns fastest.

5. *Residual Gases.* The amount of residual gases in the mixture is dependent upon the exhaust pressure, increased exhaust pressure increasing the amount of residual gas in the cylinder. An increase in residual gases decreases the combustion speed.

6. *Humidity.* An increase in humidity decreases the combustion speed.

7. *Engine Speed.* Combustion speed increases with engine speed. The increase in combustion speed in this instance is actually caused by the increase of turbulence of the charge. The turbulence is increased by the higher inlet velocities. If it were not for this increase of combustion speed with increased turbulence, the higher piston speeds of some of the present-day engines would be impossible.

8. *Time of Ignition.* The speed of combustion varies for different degrees of spark advance. As the spark is advanced the combustion speed increases to a maximum and then begins to decrease. The variation of flame speed with variation of ignition time is probably due to the difference in pressures at different ignition times. The intensity of the ignition spark seems to have no effect upon the speed of combustion. For combustion to occur, though, the spark must have sufficient intensity to ignite the charge.

9. *Fuel Composition.* Speed of combustion varies with different fuel compositions. There is no explanation of this difference.

Several factors influence the time required for the complete combustion of a charge within a cylinder, although they have no influence upon the speed of combustion. The size and shape of the combustion chamber determine the time required for the flame to travel from the ignition point to all parts of the chamber. The location of the point at which ignition occurs has a bearing upon the time required for complete combustion. In a shallow circular chamber the flame can progress from a point in the center to the circular walls in a shorter time than it can progress from one side of the circle to a point diametrically opposite. If two spark plugs were placed on diametrically opposite sides of the circular chamber and ignition occurred at both points simultaneously, a flame would start from both points at once. Com-

plete combustion would require less time than if only one of the spark plugs operated.

Any change in the time required for complete combustion in relation to piston position in the cylinder will have an effect upon the pressures within the cylinder and will therefore influence the efficiency and power output. This explains the necessity for changing the time of ignition to obtain maximum efficiency and power output when any variations occur that influence the time required for combustion in terms of piston position (crank angle).

Detonation. Detonation is a phenomenon which, by rapid pressure increases on the inner walls of the cylinder, causes a metallic, hammer-like knock. The pressure increases are brought about by pressure waves emanating from the extremely rapid combustion of the last portion of the charge to burn. The reason for the exceedingly rapid combustion of the last portion of the charge to burn is not well understood. However, several factors which influence the rate of combustion of the last portion of the charge are understood. To simplify discussion, the last portion of the charge to burn in the cylinder will be called the detonation charge.

It appears that the detonation charge is not ignited by the flame which progresses through the rest of the charge, but that it ignites itself by compression ignition. Although all fuels have a self-ignition temperature, it seems that, after the temperature is reached, a certain time must elapse for reactions to take place before ignition will occur. If, during the time required for the reactions, the flame front of the main charge can be made to pass through the detonation charge and burn it in a normal manner, no detonation will occur. This explains why a cylinder equipped with two diametrically opposite spark plugs has a greater tendency to detonate when only one plug is operating.

If the self-ignition temperature of the detonation charge is not reached, there will be no detonation. Therefore, any operating conditions which will reduce the temperature of the last part of the charge to burn will reduce the tendency to detonate. Operating conditions which will reduce detonation because of a reduction in either or both the pressure and temperature of the last part of the charge to burn are:

1. Low compression ratio.
2. Efficient cooling of the cylinder walls.
3. Retarded spark.
4. Rich mixture (delays burning and also cools).
5. Very lean mixture (delays burning).
6. Low inlet temperature.
7. Low inlet pressure.

Any condition which will cause the flame front of the main charge to pass through the detonation charge, and burn it in a normal manner before it explodes of self-ignition, will reduce the tendency to detonate. Operating conditions which will reduce detonation because of a decrease in the time required for complete combustion of the charge are:

1. Compact combustion space.
2. Small cylinder diameter.
3. Multiple spark plugs.
4. High engine speed.

The composition of the fuel used will have a bearing upon the rate of speed of combustion. However, the temperature-time-ignition characteristic of the fuel has more bearing upon whether or not the charge will detonate.

Cooling. During combustion the temperature of the gases within the cylinder becomes very high. The temperature often exceeds 4500°F. A large part of the heat from the gases is transferred to the walls of the cylinder, the piston, and the valves. If heat is not taken away from these parts as fast as it is absorbed by them, their temperatures will increase. Excessive temperatures of these parts burn the oil which lubricates them and cause preignition of the fuel-air charge and other abusive conditions. For these reasons, heat, which is absorbed by the cylinder, valves, and piston, must be conducted away from them at a sufficient rate to prevent their becoming too hot. This is the function of the cooling system.

Engines may be either liquid cooled or air cooled. The cylinders and cylinder heads of the liquid-cooled engine are made with a double wall to provide a space between them for the cooling liquid. This space for the cooling liquid is usually called the liquid jacket. It covers the entire length of the stroke to prevent unequal expansion in the cylinder bore and burning of the lubricating oil. Cooling liquid is circulated through the jacket continually while the engine is in operation. The circulation is accomplished by means of a pump. Heat received by the cooling liquid in cooling the cylinders must be dissipated in some manner. A radiator is used for cooling the liquid. The radiator is generally an assembly of small metal tubes through which the liquid can pass. The outside of these tubes is exposed to the moving air, and thus the liquid passing through them is cooled. After being cooled the liquid is circulated back to the engine to receive more heat. Actually, the liquid-cooled engine is cooled by air. The liquid is merely a medium for transferring the heat from the engine to the radiator.

If water is used as the cooling liquid, a temperature must be main-

tained below the boiling point of water to prevent the water from boiling off. A comparatively large radiator is required to maintain such a low temperature. Engines will operate successfully at temperatures above the boiling point of water. With other conditions remaining the same, the heat carried away from the radiator is dependent upon the temperature difference between the liquid to be cooled and the cooling air. The higher the temperature of the liquid to be cooled, the greater will be the rate of heat transfer to the air. If the operating temperature of the cooling liquid is increased the same amount of heat may be dissipated with a smaller radiator. Ethylene glycol, sold under various trade names, such as Prestone and Shellzone, has a boiling point of 380°F. It is generally used as the cooling liquid in liquid-cooled aircraft engines.

In the air-cooled engine the heat is transferred from the cylinder walls to the fins, and thence to the air. The amount of heat which can be radiated from the fins is dependent upon their surface area and the temperature difference between them and the cooling air. If the air is not properly circulated, it, of course, soon becomes too hot to cool properly. Hence sufficient air movement must be provided. Relative air movement is accomplished by the forward movement of the airplane during flight and is aided by the propeller blast. However, on the ground the propeller blast is the only means of circulation.

Cowling is used to aid in the proper circulation of air and to reduce the resistance of the engine to movement through the air. The higher-powered engines are equipped with suitably shaped baffles between the cylinders which force all the air entering the cowling through the space occupied by the cylinder fins.

CHAPTER III

ENGINE COMPONENTS

The basic desire in the design of an aircraft engine is to build an engine which will deliver without interruption a maximum horsepower output per unit weight of engine. The reliability of the aircraft engine is of prime importance. An aircraft is no more reliable than its power source. The low specific weight of the engine per horsepower output increases the performance of the aircraft.

In the design of an engine the principal limitations on the horsepower output are the rate of dissipation of heat, detonation, and the strength of the materials used.

The horsepower output per unit weight of engine is dependent upon the efficiency of the engine, the relative weight of the materials used in construction, and the efficiency in design of obtaining the greatest strength out of the materials used. Besides affecting the horsepower output per unit weight of engine, the efficiency also affects the economy of operation and the ratio of the heat which must be dissipated.

Other features which must be considered in engine design are: flexible and positive control, smooth operation, minimum resistance to air flow, standardized parts for interchangeability and low operation, maintenance, and overhaul cost.

Materials Used in Aircraft Engine Construction. The selection of a metal for use in an engine will be determined by: its strength; weight; resistance to wear; resistance to corrosion; adaptability to casting, forging, and machining; heat conductivity; availability; cost, and sometimes by other characteristics. Different requirements prevail throughout the engine and, hence, various metals meeting or approaching these requirements are used. The improvement in design and forging, casting, and machining technique and the advancement of metallurgy have caused and will continue to cause particular metals to be replaced by others.

Stresses within the Engine. Except in a very few parts it is not possible to calculate the stresses within an engine. However, with the aid of previous and similar design, it is possible to determine fairly well where the maximum stresses will occur and to approximate their magnitude. The most useful tools with which the engine designer has to

work are the design geometry of previously successful engines and their integral parts and the experimental laboratory.

As would naturally be expected, the most highly stressed parts of an engine are those which are in line with the fire of the cylinder. Such parts are pistons, piston pins, connecting rods, cylinder hold-down bolts, and other parts. Of course, those parts which transmit the power longitudinally to the output shaft are also highly stressed.

Few of the forces within the engine which produce stresses in the component parts are steady in either direction or magnitude. Because of this, it is necessary to design the parts of an engine stronger than if the loads were steady. Metals fatigue when they are subjected to reverse bending moments. The fatigue in metals is cumulative; that is, the metal does not recuperate from the fatigue by standing idle after bending. An illustration of fatigue and eventual failure is the bending of a piece of wire back and forth until it breaks. In this case, the metal is actually stressed past its elastic limit, but the principle is similar in cases where the elastic limit is not reached.

As the number of reverse bendings increases the ultimate strength of the metal decreases. This decrease in strength is rather rapid at first, but then begins to decrease less rapidly. The strength of the material in the region where decrease in strength is not so rapid must be the strength which is considered in the design of engine parts. Various metals have various fatigue characteristics. Also, the heat treatment to which a metal has been subjected has an effect upon its fatigue characteristics.

Heat treatment is a rather broad term used to cover all heating and cooling processes and techniques which affect the grain structure and strength of metals. By heat treatment, the majority of metals may be given various physical characteristics. Thus, we may find the same metal or metal alloy used in different parts of an engine with the unit strength of the metal different in each part.

The effect of temperature on the strength of metals must also be considered in engine construction. The strength of some metals is reduced considerably as the temperature rises. The strength of an aluminum alloy cylinder head at operating temperatures is much less than it is when cold.

In the design of any part it is the desire of the designer to avoid stress concentrations at any point. Stress concentration points are those points at which failure first occurs. Once the failure has commenced its propagation is rapid until complete failure of the part results. The ideal design would be one which distributed the stresses evenly throughout the part. However, this is impossible in most cases because

of other design limitations. Also, changing load directions would alter the stresses in a part designed to distribute evenly stresses from a steady load in one direction.

The greatest producer of stress concentration is the sharp inner corner. If a load were applied to a part as shown in Fig. 26(*a*), which has an absolutely sharp corner, the stress concentration at the corner would be infinitely large. Actually, it is not possible to have

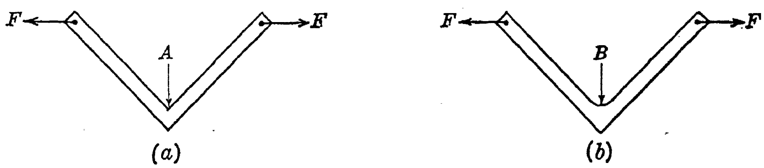


FIG. 26. Stresses caused by sharp corner. When the forces *F–F* are applied, the unit stress at the sharp corner (*A*) is extremely high. The unit stress of the corner is greatly reduced by the use of a radius as at (*B*).

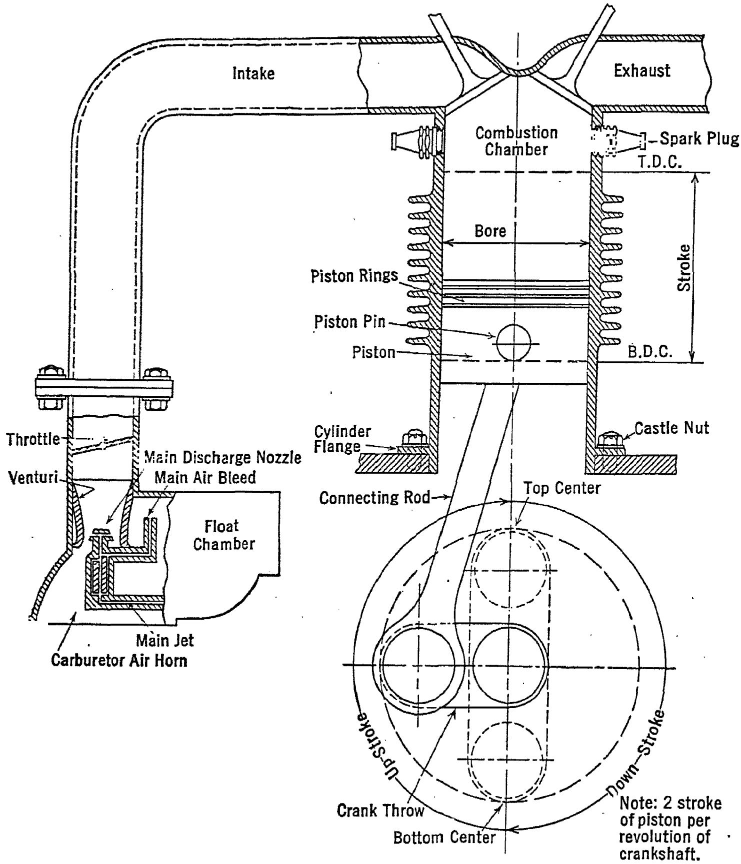
an absolutely sharp corner. Even if it were, there would be a flow of metal when stresses were introduced, and the corner would be no longer absolutely sharp. However, the stresses in a relatively sharp corner are extremely high. To reduce these stresses a fillet is placed in the corner as shown in Fig. 26(*b*). The larger the radius of the fillet the greater the reduction in stress concentration. Throughout the complete construction of a well-designed engine it will be noticed that the most generous radii allowable are used on all corners.

Pistons. The gas pressure within the cylinder acts upon the piston, pushing it toward the bottom of the cylinder. The work done on the piston is transmitted, through a connecting rod, to the crankshaft where the work is transformed into rotary motion. The piston is the first part actually to receive the work from the cylinder gases.

The top of the piston, against which the gases exert pressure, is called the piston head. The lower part, which may be split to allow for expansion, is called the skirt. The protruding masses of metal within the piston, through which the piston pin passes, are called bosses. The piston pin is that pin which passes through and connects the piston to the connecting rod. Grooves in the piston carry the piston rings. The solid portions between the piston ring grooves are known as lands.

Aircraft engine pistons are almost invariably made of aluminum alloy forgings. Aluminum alloy is light and it is a very good heat conductor. The head of a piston may be either flat, concave, or convex. Sometimes, irregular shapes are used in an effort to increase turbulence of the incoming fuel-air charge. Indentations are often

machined in the piston head to clear the valves when the piston is at top dead center. The underside of the piston head is often provided with fins or other protruding surfaces to aid in cooling.

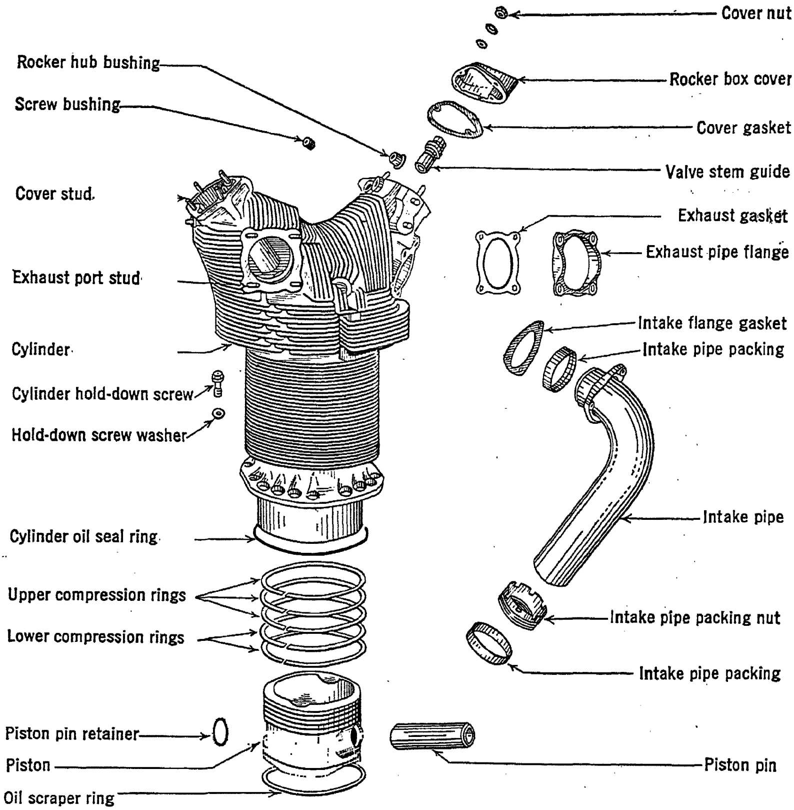


Courtesy Civil Aeronautics Administration

FIG. 27. Engine nomenclature sketch.

Piston Pins. Piston pins are tubular, are made of high strength steel, and are ground to a very smooth finish. They may be secured to the connecting rod and left free in the piston. They may be secured to the piston and left free in the connecting rod. However, general practice is to leave the piston pin free in both the piston and the connecting rod. Such a pin is called full floating. Some means is always provided to prevent the piston pin from moving longitudinally and coming in contact with the cylinder walls, which it would wear and

score. Endless coil springs, snap rings, aluminum plugs, and other means are provided for this purpose. Piston pins are most generally lubricated by oil mist emanating from the master rod bearing, knuckle pin bushings, and oil jets.



Courtesy Wright Aeronautical Corporation

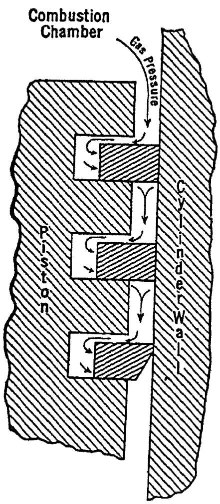
FIG. 28. Air-cooled engine cylinder and piston assembly.

Piston Rings. To prevent the gas pressure within the cylinder from escaping past the piston sides the piston is provided with rings. The top rings are referred to as compression rings and the lower ones are usually called oil and scraper rings. The shape, size, arrangement, and number of rings for optimum results is something which has never been definitely determined. Each engine manufacturer will prefer certain ideas. The best that can be said of piston rings is that if they work satisfactorily they must be all right. Most piston rings are

made of cast iron. The rings must retain their elasticity so as to exert pressure on the cylinder walls at all times. Cast iron has considerable elasticity which is unaffected by the heat at engine-operating temperatures. It also has a relatively soft texture so that it does not tend to score the cylinder walls.

FIG. 29. Various piston ring end joint shapes.

For installation purposes piston rings cannot be a continuous circle; they must be split. Various shapes are used at the split joint. Several may be seen in Fig. 29. The diagonal cut and the lap joint, as shown in views (*a*) and (*b*) respectively, are in most general use. At installation, the rings must be correctly fitted with a proper end clearance provided at the joint to allow for expansion.



30. Sealing effect of gas pressure on piston rings.

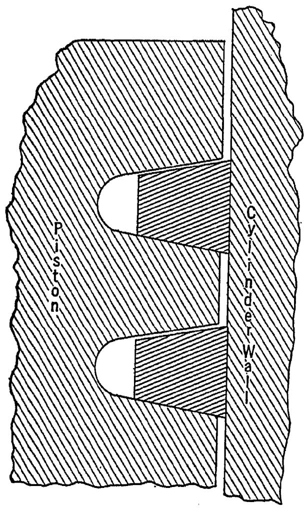


FIG. 31. Wedge-shaped piston rings.

The effect of gas pressure on the piston rings is shown in Fig. 30, which is exaggerated for clearness. Besides the elasticity of the piston rings, the gas pressure from the combustion chamber also helps to push the piston rings outward against the cylinder walls. The greatest amount of pressure is exerted on the top ring. The gases which escape

by the first ring travel down the piston side and behind the second ring. If the top two rings are working satisfactorily there will be very little pressure on lower rings. A ring shaped like the third ring may exert just as much pressure on the cylinder wall per unit area as one of the rings above. The pressure behind that third ring is less than that behind either of the other rings, but this total pressure is concentrated against the cylinder wall in a smaller area and, hence, the force per unit area is greater than it would be if the ring had a full face.

Wedge-shaped piston rings, as shown in Fig. 31, are used quite often. The use of such rings increases the thickness of the ring lands at their roots, thus resulting in greater land strength. Also, rings of this type do not have as much tendency to stick as rings with parallel upper and lower surfaces.

The oil and scraper rings are arranged in various ways. Some bottom rings scrape oil upward and depend upon a higher ring to scrape the oil from the cylinder walls and discharge it through drain holes in the piston back to the crankcase. Such an arrangement may be seen in Fig. 115 (page 136). Most bottom rings scrape the oil downward. Regardless of the arrangement, the manufacturer has tested the arrangement and proved it to be satisfactory. Rings should never be installed in a piston in any manner except that prescribed by the manufacturer.

Cylinders. The cylinder is that chamber in which burning and expansion of the gases occurs and in which the piston moves as the gas forces are exerted upon it. Some means must be provided for inducting the fresh fuel-air change, for igniting the mixture, for cooling the cylinder, and for expelling the burned gases.

Cylinders of in-line engines may be cast en bloc with others or they may be individual. Cast aluminum cylinders have steel sleeves installed for wear purposes. If the cylinder is to be liquid cooled a liquid jacket must be provided around the cylinder.

Air-cooled cylinders are cooled by fins machined on the barrel and cast on the head. The complete cylinder barrel of some cylinders is made of steel. Others have a steel inner barrel onto which is shrunk a finned aluminum alloy outer barrel. Aluminum is a better conductor of heat than steel and deeper fins can be machined in it.

The heads of air-cooled cylinders are of cast aluminum alloy. The strength of the cast aluminum cylinder head is probably now the limiting factor in the output of air-cooled engines. The strength of aluminum alloy is greatly reduced with increasing temperature. This is the main reason why it is so important to keep the cylinder head temperatures below a particular prescribed maximum. As forging, casting, and heat treating technique improve it is most likely that air-cooled

cylinder heads will be made of steel. At elevated temperatures steel is much stronger than aluminum alloy per unit of weight.

The cylinder heads are screwed and shrunk onto the cylinder barrel. Valve guides, valve seats, spark plug bushings, and rocker arm bushings are shrunk into the cylinder head. Shrinking is accomplished by heating the cylinder head; this causes it to expand. With the head expanded and the barrel, valve seat inserts, and other parts cold, they are put in place. When the head cools, it shrinks, producing a tight fit around these parts.

As the cylinder head shrinks it reduces the top of the barrel several thousandths of an inch in diameter. If the inner walls of the cylinder barrel are ground to size after the head is shrunk on, the inner wall diameter will be the same throughout the length of the barrel. This is known as a straight bore cylinder. However, if the barrel is ground before the head is shrunk on, after assembly the diameter at the top of the barrel is less than at the bottom. Such a cylinder is known as a choked bore or tapered bore cylinder. During operation the top of the cylinder becomes much hotter than the bottom and the expansion gives the barrel an almost straight bore. More piston ring end-clearance must be provided for choked bore cylinders than for straight bore cylinders.

To reduce wear the cylinder walls of modern engines are hardened by a nitriding process. The nitride hardening only penetrates a few thousandths of an inch. Therefore, nitrided cylinders cannot generally be reground as the nitrided metal might be completely ground from the high portions of the wall.

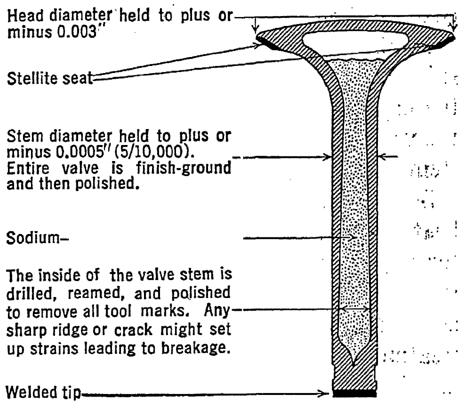
Valves, Valve Inserts, Valve Guides, and Valve Springs. The function of the valve mechanism is to admit the fresh charge into the cylinder, seal the charge within the cylinder during compression and expansion, and then allow the burned gases to be discharged from the cylinder. In the design of such a mechanism consideration must be given to providing a large and efficient passage, good cooling of the mechanism, and the insurance of a tight seal when the valves are closed.

The *poppet-type valve* has been generally accepted as the best mechanism for meeting the above requirements. There are many ways in which the valves may be arranged with relation to the combustion chamber. However, the most general practice is to place the valves in the head of the cylinder directly over the barrel. In an effort to increase the passage area, more than one exhaust valve and intake valve is sometimes used. A smooth and continuous passage without abrupt bends, sharp corners, or protruding surfaces is conducive to the most efficient passage. The angle of the valve face affects both the

efficiency of passage and the sealing. The valve face angle is usually 30° or 45°. Recent tests tend to indicate that the 45° valve face angle permits better passage than the 30° angle. It is also contended that the steeper angle of the 45° face permits better wedging action than the 30° face, resulting in better sealing and producing less tendency for the valve to bounce.

Valve insert seats, against which the valve faces rest to provide the seal, are generally shrunk into the cylinder head. To prevent loosening at the inserts when the cylinder head becomes hot, the expansion characteristic must be considered in selecting a metal for valve inserts. Valve seats and valve guides on low powered engines are usually made of aluminum bronze. This metal has good heat-dissipating properties and therefore does not overheat rapidly. It is often used for the intake valve seats on high powered engines. The exhaust valve is subjected to much more heat than the intake valve. On high powered engines the exhaust valve inserts are made of high temperature, noncorrosive steel.

The only cooling which the valves receive is through contact with the cylinder head at the valve guides and the valve seat. Since the exhaust valve has more need for cooling than the intake, the exhaust valve seat face is usually made wider than the intake seat to provide more surface for cooling.



Courtesy Thompson Products

FIG. 32. Sodium-cooled valve. (*Caution:* Discarded sodium-cooled valves should never be machined or ground because of the danger of severe burns to the operator if the sodium should come in contact with air. Discarded valves should be thrown into deep water or otherwise permanently disposed of.)

Exhaust valves of solid steel may reach temperatures as high as 1450°F or more. Such a temperature is too high for satisfactory operation. The high temperature, noncorrosive steels of which valves are made are very poor conductors of heat. To aid the valves in conducting heat away rapidly, thus keeping the valves cooler, valves may be made hollow and filled with a good heat conductor. The construction of such a valve is shown in Fig. 32. The valve has a hollow cavity in the head and a hollow stem. This space is filled from 40 to 70 per cent

full with metallic sodium. The metallic sodium is about six times as good a heat conductor as the valve steel. It is of about the same weight as water. The sodium melts at about 200°F; this means that it is liquid at operating temperatures, but its boiling point is high enough to prevent it from boiling at operating temperatures. Since during operation the sodium is liquid, heat is carried away from the hot valve head to the cooler stem, by circulation as well as conduction, as the liquid splashes with the motion of the valve. The sodium is sealed in the valve by welding at the top end.

Austenitic steel, although hard to forge and machine, is the best metal which has been developed to date for exhaust valves. It has very good hot strength, corrosion resistance, and impact strength. Other metals, such as high tungsten steel and cobalt-chromium steel, are used in exhaust valve construction, but they do not have the desired characteristics of the austenitic steel.

Intake valves are commonly made of chrome-nickel steel and tungsten steel. Since the intake valves do not require the cooling which the exhaust valves do, they are seldom sodium cooled and, therefore, the valve stems may be made solid and smaller than the exhaust valve stems.

Some of the steels used in valve construction cannot be hardened by heat treatment. To provide a hard tip at the end of the valve stem for preventing excessive wear, a tip of metal which can be hardened is welded onto such valves. The valve stem should be hard so as to provide a good bearing surface against the guide. By a nitriding treatment the stem surface may be given a file hardness about 0.005 in. deep.

The *valve seating face* may be of the valve metal itself, or another metal may be puddled on to make the valve face. Stellite, because of its high, hot hardness and corrosion resistance, is superior to any valve face metal so far developed.

During engine operation the *valve head* becomes hotter than the valve seat insert in the cylinder. This difference in temperature causes the valve head to expand more than the insert and consequently the valve climbs higher on its seat. Therefore, the contact surface of the valve face against the insert seat is not the same when operating as it is when cold. Consideration must be given to this when refacing valves and inserts.

Valve faces are made wider than insert faces. When cold and in the closed position, the face of the valve projects past the face of the insert 0.015 to 0.025 in. on both the passageway and combustion chamber sides. As the valve expands more than the insert during opera-

tion, more of the valve face projects into the combustion chamber than into the passageway.

Some valves and inserts are given an "interference fit." The valve face and insert face are ground at slightly different angles. This provides seating only at the outer edge of the insert, but with higher unit pressure than if the complete face surfaces mated.

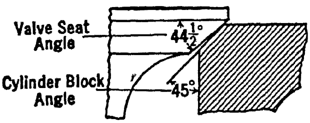


FIG. 33. Interference fit between valve face and valve seat face. Unit pressure at point of contact is high, helping to aid sealing and prevent guttering.

Valve guides are commonly constructed of aluminum bronze. They must be accurately reamed to provide a good fit with the valve stem. Loose-fitting guides will allow the valve to wobble in its seat and prevent good sealing. The advent of circulated lubrication to the valve mechanism has reduced the clearance necessary between valve stems and valve guides, because of the assurance of positive lubrication and the lighter oil used. Most of the cooling of the valve is through the guide. Heat is conducted away from the guide by the cooling of the cylinder head and the cooling afforded by the lubricating oil.

Valve springs are constructed of high grade spring steel wire. They are wound spirally and ground flat at each end to insure even distribution of pressure. Several springs are generally nested one inside the other. The tension of the spring or springs is such as to insure that the valve cam follower will not leave the cam at maximum operating speed. Springs are held in place by a spring retainer secured to the end of the valve stem. Several methods are employed for securing the retainer to the valve stem. Probably the most popular method is the split-type wedge collar as shown in Fig. 34. In the event the retainer becomes unattached from the stem or a spring breaks, a safety retainer is sometimes provided to prevent the valve from dropping into the combustion chamber. The safety retainer is usually a small snap ring which fits into a groove in the valve stem and prevents the stem from sliding in the guide past the snap ring.

Valve Cam Mechanism. There are two main considerations in the design of a valve cam mechanism. First, what should be the motion of the valve with relation to crankshaft rotation, or piston motion, to provide the most efficient inlet of the fuel-air charge and exhaust of the burned gases? Second, what mechanical design is most suitable for opening and closing the valves?

One's first thought might be that the most efficient intake valve mechanism would be one which would open the intake valve instantly, hold it full open until the full charge was in the cylinder, and then allow

it to close instantly. However, this is neither the most efficient mechanism, nor is it mechanically possible. The demand for fuel-air charge by the cylinder is dependent upon the downward velocity of the piston. The downward velocity of the piston with relation to the crankshaft rotation increases from a minimum at top dead center (T.D.C.) to a maximum when halfway down and then diminishes, again reaching

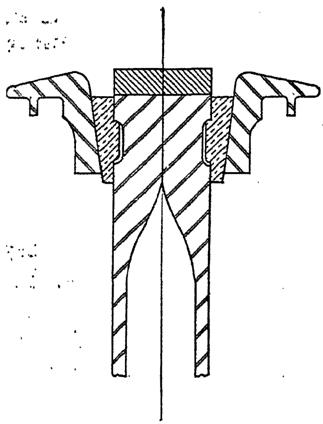


FIG. 34. Valve spring retaining washer and lock.

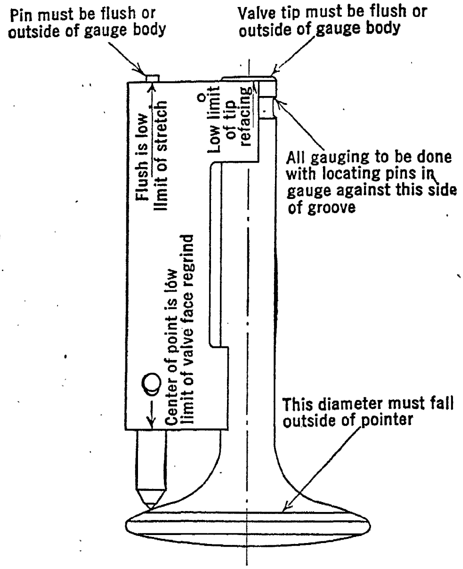
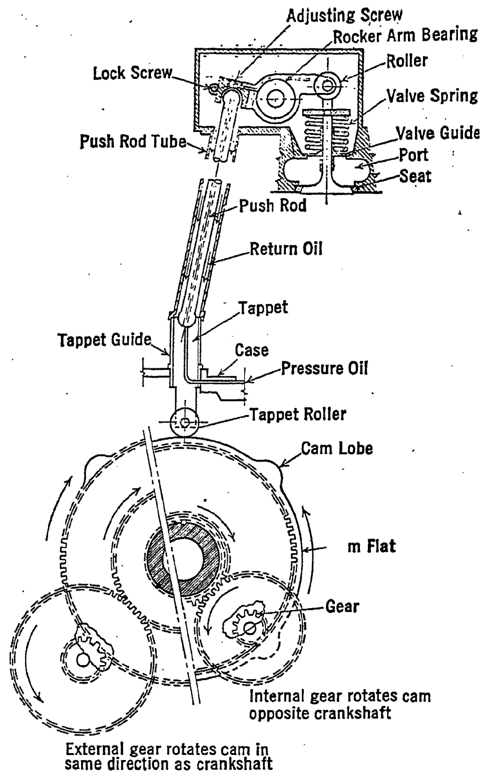


FIG. 35. Limit gauge for checking stretch of valves.

zero at bottom center, as illustrated by the sine curve of Fig. 37. If the fuel-air charge acted as a noncompressible fluid, the valve area opening should increase and decrease with the demands of the cylinder. This would result in a cam in the shape of the curve in Fig. 37 for opening and closing the valve. However, the fuel-air charge is not a noncompressible fluid. When the charge enters the cylinder it expands, and if the valve is left open after bottom center, air will continue to flow into the cylinder to equalize the pressure inside and outside the cylinder. Intake valve closing is, therefore, delayed past bottom center to allow the cylinder to fill to the pressure in the inlet pipe. The amount of delay in closing necessary to assure the greatest amount of charge entering the cylinder is dependent upon the engine speed. The amount of delay increases with speed. The engine designer selects the speed at which optimum results are desired.

Prior to the opening of the exhaust valve the pressure within the cylinder is much greater than without. It is desirable to reduce this pressure in as short a time as possible so as to minimize the heat flow to the valve seats and guides during "blowdown" and also to prevent the pressure from acting on the piston during its up stroke. The "blowdown" occupies considerable time and to minimize the amount of pressure acting on the piston during its up stroke the exhaust valve commences opening before bottom center. As in the inlet valve, the exhaust valve closes after top center. The amount of delay is much less than that of the inlet valve because of the lower density of the exhaust gases and the smaller volume in the cylinder with the piston at the top of its stroke.



Courtesy Civil Aeronautics Administration

FIG. 36. Schematic view of radial engine valve mechanism.

From a mechanical standpoint, the most desirable cam form is that of a sine curve. The complete cam mechanism should be designed so that the cam follower will continuously remain in contact with the cam at full speed operation. A flat-topped cam is illustrated in Fig. 39. At very slow speeds the cam follower will follow the contour of the cam form. As the speed is increased the follower will leave the cam and follow path (*a*). A further increase in speed may cause the follower to follow path (*b*) which is a sine curve. If this should be the maximum operating speed, the cam might just as well have been formed in the contour of path (*b*), since this is the path the follower will take regardless of the flat top. A further increase in speed or a weak valve spring will cause the follower to take the sine curve (*c*).

To assure complete closing of the valves it is necessary to leave a slight clearance in the valve-operating mechanism. A gradual sloping ramp takes up this clearance as the cam follower approaches the cam. After the follower leaves the ramp it first contacts the accelerating portion of the cam and then the main actuating portion of the cam. The maximum cam lift is usually one-quarter the diameter of the valve face. Experiments have shown that opening a valve more than one-quarter the diameter of its face adds very little to the flow of air through the opening.

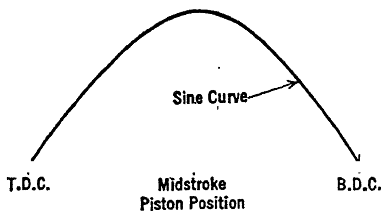


FIG. 37. Curve of cylinder demand for charge vs. piston position.

The motion of the cam follower is transmitted through push rods and rocker arms to the valve stem. As the cylinders of an engine become hot during operation they not only expand in diameter but also elongate. Since the cylinders of an air-cooled engine reach a much higher temperature than the valve push rods they elongate more than the push rods. This increases the valve clearance to a value known as the *hot* or *timing* clearance. As the valve clearances are normally adjusted and checked while the engine is cold, the cold as well as the hot clearance valves are specified on the engine data plate.

Connecting Rods. The lineal motion of the pistons is transformed into rotary motion of the crankshaft through connecting rods. The connecting rods of high output engines are made of high strength alloy steels,

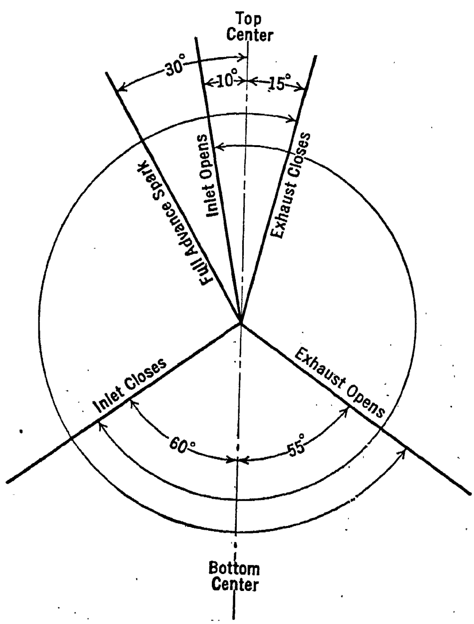


FIG. 38. Typical valve-timing diagram of an air-cooled aircraft engine.

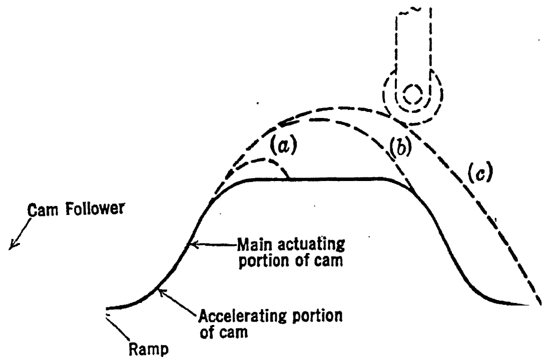


FIG. 39. Flat-topped cam lobe showing path of cam follower as speed is increased.

forged and machined to an extremely smooth finish. The shank section of the rod is usually in the shape of an I or an H to afford the greatest strength per unit of weight. The lighter the connecting rods the lighter the crankshaft counterweights may be. Some of the low output engines employ a forged aluminum alloy for connecting rod construction. This alloy, known by the trade name of Lynite, is itself a good bearing material and where it is used it is not necessary to place a bearing bushing in the connecting rod ends.

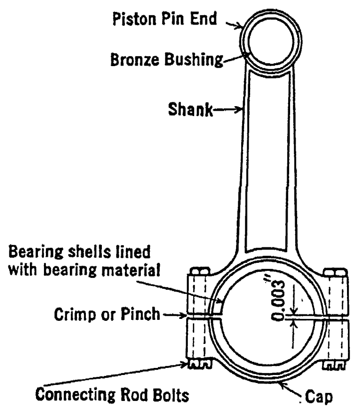
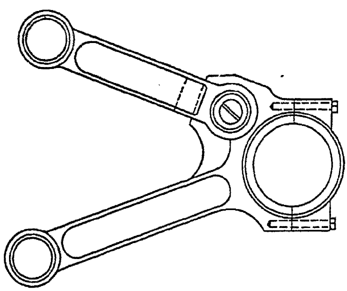


FIG. 40. Conventional connecting rod used in opposed and in-line engines.

Steel connecting rods are fitted with a bearing at both ends. The bearing which receives the piston pin is generally made of bronze. The bearing at the big end of the connecting rod, which attaches to the crankpin, may be made of silver alloy, silver-cadmium-zinc alloy, lead-bronze, or other alloy. Babbitt is too soft for the high bearing pressures encountered in the high output engines. The bearing metals are generally backed with a steel shell.

The connecting rods of a V-type engine, or other type of engine in which two connecting rods attach to the same crankpin, may be constructed in several different ways. Two connecting rods exactly alike may attach to the same crankpin, one behind the other. In this event

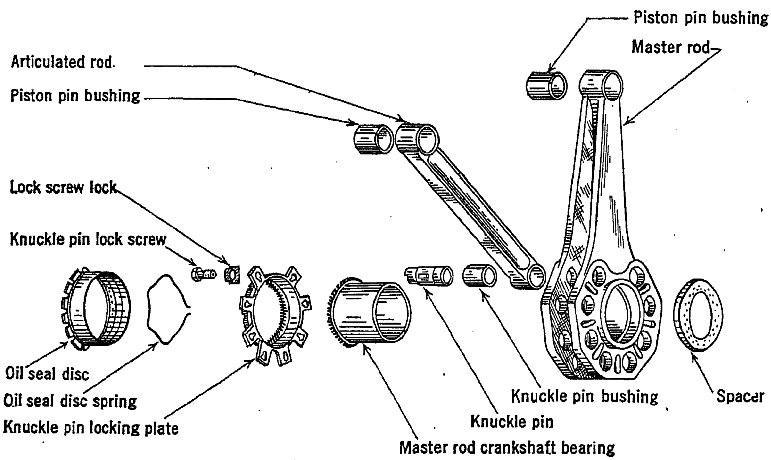
it is necessary that the cylinders of one bank be placed farther back than those of the other bank to allow the connecting rods to center the pistons. One connecting rod may be in the shape of a fork at its big end, allowing the rod from the other bank to fit in between the prongs of the fork. The rod between the prongs of the fork may clamp around either the crankpin or the outer surface of the forked rod. An articulated rod may be seen in Fig. 41. Only the master rod connects to the crankpin; the articulated rod connects to the master rod.



Courtesy Civil Aeronautics Administration

FIG. 41. Articulated connecting rod (used in V-type engines).

Radial engines utilize the articulated rod construction. The master rod is either one piece or split, depending upon whether the crankshaft is split or solid. The articulated rods are connected to the master rod with knuckle pins. Several different methods are used for securing the knuckle pins in place. An oil bleed



Courtesy Wright Aeronautical Corporation

FIG. 42. Exploded view of a radial engine articulated connecting rod assembly, with only one of the articulated rods shown.

from the master rod main bearing lubricates the articulated rod knuckle pin bearings.

The geometry of the articulated connecting rod assembly is such

that it is necessary either to have articulated rods of slightly different lengths or to place the knuckle pins at different distances from the center of the master rod main bearing in order to obtain the same compression ratio in each cylinder. In order that the articulated rods may be interchangeable they are all made the same length and the distance from the center of the main bearing to the center of knuckle pins is made different.

Another peculiarity is brought about by the geometry of the articulated rod assembly. The master rod's travel is circular, since it is attached to the crankpin. However, since the centers of the knuckle pins do not always remain on a straight line connecting the piston pin centers with the crankpin center, their motion is elliptical. This causes the pistons attached to articulated rods to reach top dead center either early or late in relation to degrees of crankshaft rotation. In extreme cases this difference in timing between the master rod piston and articulated pistons may vary as much as plus or minus 6° crankshaft rotation. In order to compensate for this difference and assure that each cylinder fires when the piston is the same distance from top center, a compensated magneto is used. There is a lobe for each cylinder on the cam of a compensated magneto so located that firing occurs when each piston is the same distance from top center.

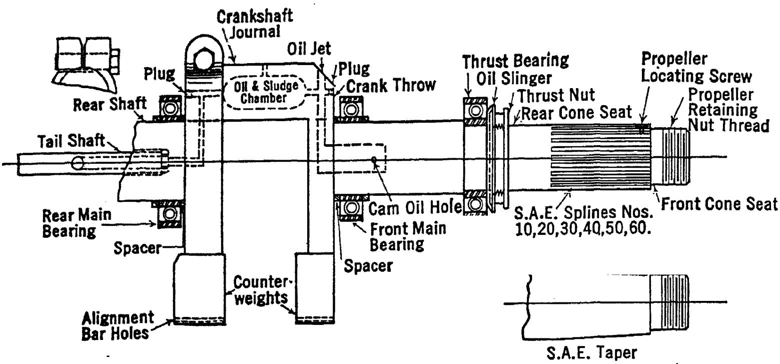
Crankshafts. The reciprocating motion of the pistons is transformed into rotary motion of the crankshaft and thence, either through gears or by direct drive, to the rotary motion of the propeller. The shape and length of the crankshaft is, of course, dependent upon the arrangement of the cylinders. The crankshaft throws must be so arranged that the same number of degrees of crankshaft rotation brings pistons of successive firing cylinders to top center.

Crankshafts are machined from forged and heat-treated high strength alloy steel. The bearing journals are usually made hollow. Hollow journals provide oil passages for lubricating oil. Crankshafts with hollow bearing journals are stronger per unit weight than solid crankshafts. The journal surfaces are generally given a nitriding treatment to make them more resistant to wear.

The crankshaft supporting bearings of in-line engines are the solid journal type. Those of the radial engine are usually ball or roller bearings. The ball bearing is preferable in radial engines because it is much narrower than other type bearings.

The crankshafts of radial engines may be made in a solid piece or may be split at the crankpin. If the crankshaft is solid it will be necessary to use a split master rod. Several methods are in use for securing together the components of a split crankshaft. The crank-

shaft illustrated in Fig. 43 utilizes a friction joint. The rear crank cheek is made in the form of a clamp which fastens around the crankpin and is held in place by friction. At assembly the rear section of the crankshaft is aligned with the front section by the use of an alignment bar inserted through alignment holes in the front and rear counterweights, while the crankshaft is held in a suitable jig. The proper amount of tension on the clamp bolt is attained by measuring its elongation during tightening.



Courtesy Civil Aeronautics Administration

FIG. 43. Schematic layout of a radial engine split-type crankshaft.

The crankshaft counterweights are so designed as to counterbalance the rotating and reciprocating weights attached to the crankpin. The articulated rod assembly of a radial engine is relatively heavy and requires a relatively heavy counterweight. Double-banked radial engines do not require such heavy counterweights as a single bank because the two crankpins are 180° apart and act as counterbalances to each other. However, since the crankpins are not longitudinally opposite each other, counterweights are necessary to prevent an out-of-balance couple. Two- and four-cylinder opposed and six-cylinder in-line engines, where the crankpins are located so that they tend to balance each other, are not always provided with counterweights. Perfect balance is not obtained, though. Since the crankpins are not longitudinally opposite each other, the forces on each tend to pull the shaft out of line at its particular location. These pulls at different locations along the shaft, although opposite to each other and of the same magnitude, tend to make the shaft wobble.

Counterweights may be forged as an integral part of the crankshaft or may be made separate and attached by some suitable means. Radial engine counterweights are usually made separate and bolted or riveted

onto the crankshaft counterweight cheeks. Where dynamic dampers are used they are made a part of the counterweight assembly. These dampers are discussed on page 328.

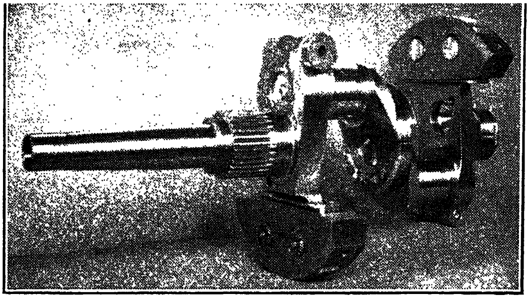


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FIG. 44. Double-row radial engine split-type crankshaft.

Crankcases. The crankcase is the main body about which the engine is built. It affords rigidity for the entire engine structure; it serves as a base to which the cylinders, crankshaft, and other components are attached; it serves as a medium of attachment of the engine to the aircraft, and it transmits the thrust from the propeller to the structure of the aircraft. It also serves as a container to prevent the loss of lubricating oil.

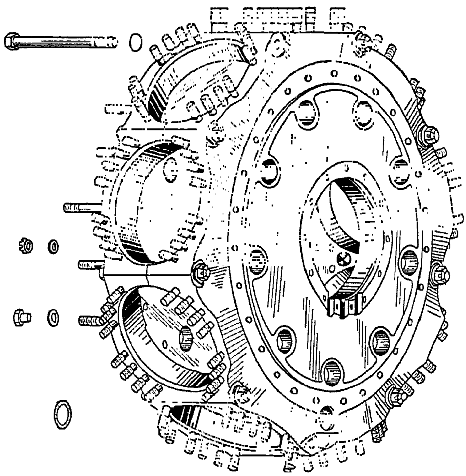

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FIG. 45. Aluminum alloy crankcase of a 9-cylinder radial engine.

The shape and detail construction of the crankcase are dependent upon the cylinder arrangement and the design ideas of the manufacturer. Low powered engines usually utilize a cast aluminum alloy crankcase. For greater strength and an assurance of more uniform metal the higher powered engines use a forged aluminum alloy or steel crankcase. Through refinement of design one radial engine manufacturer has been able to produce a forged steel crankcase which weighs approximately the same

as the aluminum alloy case previously used on similar engines. The steel case is stronger than the original aluminum alloy case. It permits the use of cap screws in place of studs and nuts for holding the cylinders in place. Also, it is easier to inspect for cracks at overhaul as it lends itself to the Magnaflux inspection process.

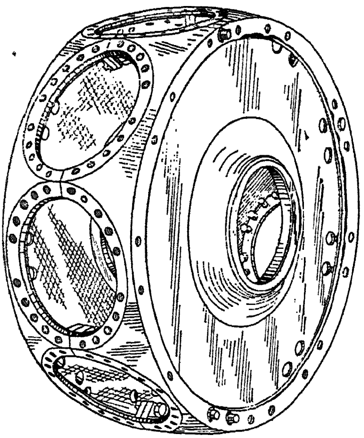

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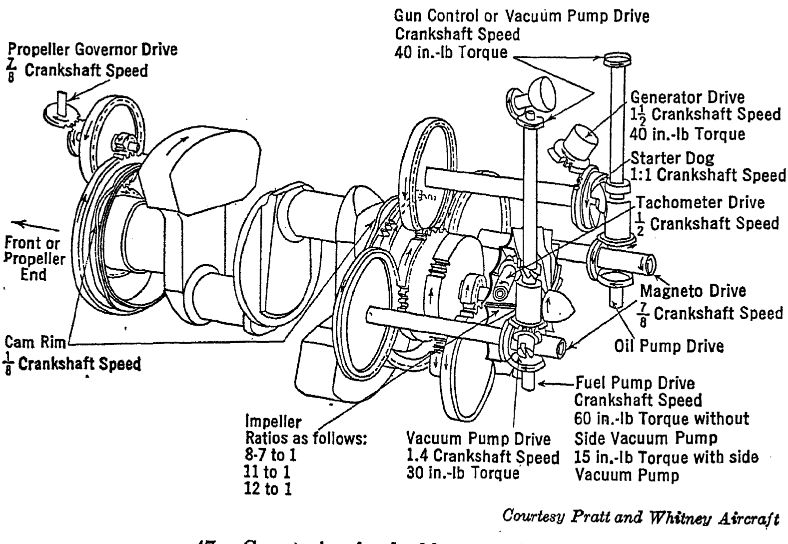
FIG. 46. **Steel** crankcase of a 9-cylinder radial engine.

Single-row radial engine crankcases are generally made in two sections which part at the center line of the cylinders. The two sections are joined with bolts which pass through both sections. Twin-row radial engine crankcases are made in three sections.

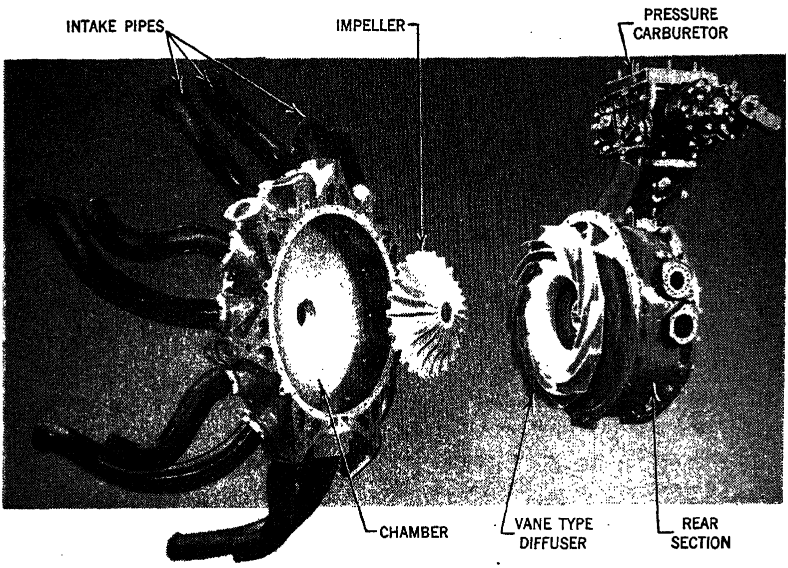
The nose section, which carries the thrust bearing and the reduction gears if the engine is geared, is attached to the front of the crankcase. The diffuser section of a radial engine is located directly aft of the crankcase and behind this section is the rear or accessory section.



Courtesy Pratt and Whitney Aircraft

47. Gear train of a double-row radial engine.

Superchargers. The external exhaust-driven supercharger must be so located that its driving turbine may receive the exhaust gases with the least flow loss in piping and also so that the flow loss in the induction system is at a minimum. The exhaust turbine is directly connected to the centrifugal blower in the induction system. The speed of the



Courtesy Wright Aeronautical Corporation

FIG. 48. Exploded view of the induction system of a 14-cylinder double-row radial engine.

turbine, and hence the pressure at the cylinder inlet ports, may be regulated by a valve which either directs the exhaust gases to the turbine or diverts them to the atmosphere. The carburetor is usually located between the blower and the cylinder inlet ports. In such an installation it is necessary to provide some metering control in the carburetor to take care of the changing air density, since a carburetor normally meters fuel in proportion to the volume of air metered through it and without regard to the mass (weight) of air metered.

The internal impeller type of supercharger is best adapted to the radial-type engine. The fuel-air mixture is compressed after the air has passed through the carburetor. In this type of supercharger the impeller, which is a centrifugal blower, receives the fuel-air mixture at the center and imparts a high velocity to it. The high velocity mixture is discharged through diffuser vanes in which the kinetic energy

is changed into pressure energy. The diffuser vanes conduct the fuel-air mixture to the cylinder intake pipes. The impeller is geared to the crankshaft and rotates at approximately ten times crankshaft speed.

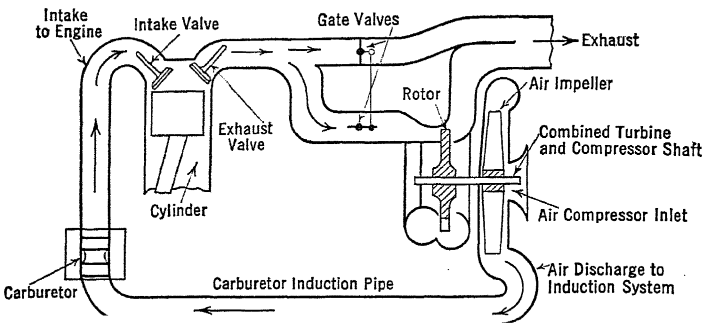
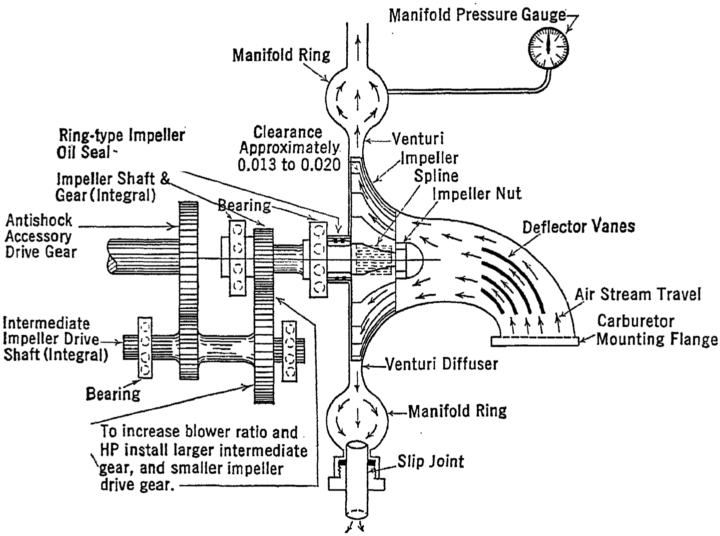


FIG. 49. Schematic diagram of an exhaust-driven turbine supercharger.



Courtesy Civil Aeronautics Administration

FIG. 50. Schematic diagram of an internal gear-driven supercharger (single ratio, single stage).

The impeller is usually driven through a fluid, friction, or spring coupling to reduce high stresses which might be induced by vibration and abrupt changes of crankshaft speed.

Some impellers are geared so that they may be driven at two or

more speeds with relation to crankshaft rpm. A clutch operated by engine oil pressure and controlled by a valve on the rear section controls the chain of gears driving the impeller, each chain of gears driving the impeller at a different ratio.

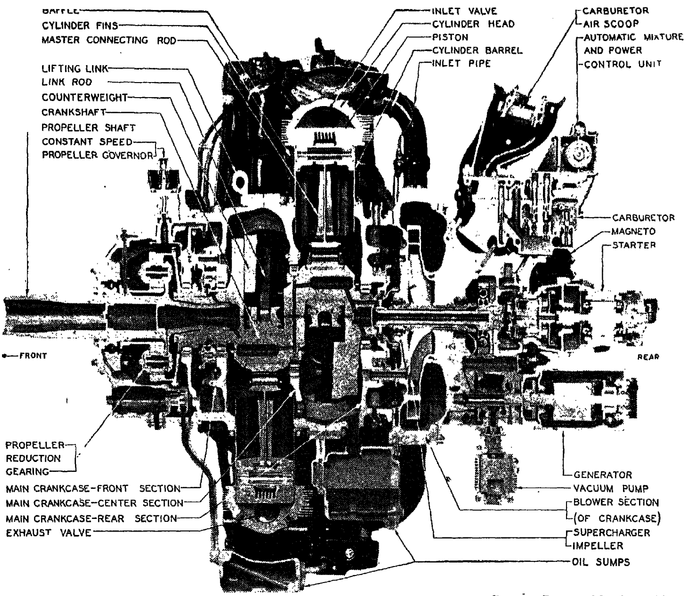
When using the geared type of supercharger the air pressure in the induction system is first reduced by a partial closing of the throttle valve (except during full open throttle operation) and is then increased again by the impeller. The power consumed by the impeller in raising the pressure after it was reduced is power that need not have been expended if the pressure had not been reduced. Yet it is necessary to reduce the pressure to control power output. Such a loss of power is not encountered in the external exhaust type of supercharger since the pump, when pumping, always receives atmospheric (unthrottled) air. To reduce such losses at low altitude the two-speed supercharger was developed for high altitude engines. With the impeller in low gear, less throttle closing is necessary to maintain a certain pressure at the cylinder inlet ports than when in high gear.

Cylinder Arrangements. The size and number of cylinders of an aircraft engine are dependent upon the desired horsepower output of the engine. The arrangement of the cylinders and the method of cooling them is a matter of choice for the manufacturer. Many words have been written and spoken concerning the advantages and disadvantages of the various methods of cylinder arrangements and methods of cooling, and it is not the intent here to try to point out any such advantages or disadvantages.

All radial engines manufactured in this country so far have been the air-cooled type. It is very probable, though, that liquid-cooled radial engines with several rows of cylinders will be developed. The double-row 18-cylinder radial engine is the largest developed in this country so far. The double-row radial engine is virtually two single-row radial engines combined. The rear row of cylinders is staggered between those of the front row and baffled in such a way as to assure proper cooling.

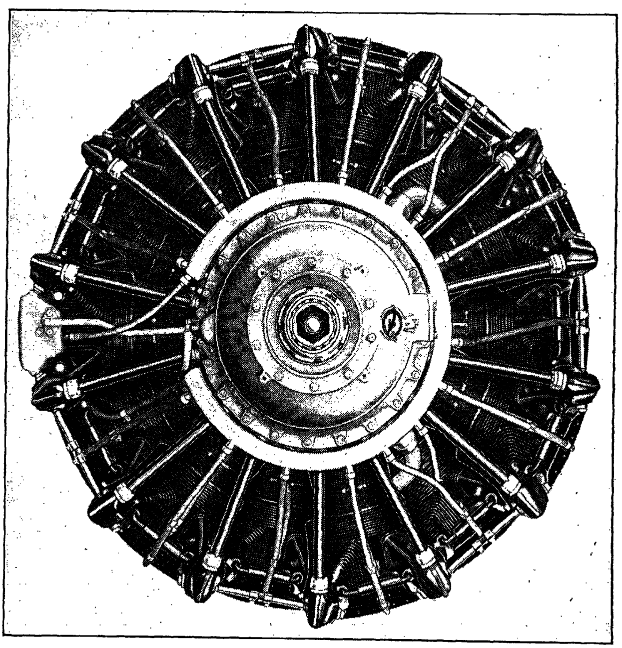
In-line engines are of both the liquid- and air-cooled type. Six is about the maximum number of cylinders used in one line. As the number increases beyond this the problem of torsional vibration of the crankshaft must be given considerable attention. Two or more lines of cylinders may be disposed about the crankcase in a manner to form several arrangements, such as the V-type engine, the I- or opposed-type engine, the double V, the X, the H, and other types.

The securing flanges of air-cooled cylinders fit against a smoothly machined surface on the crankcase known as the cylinder pad. The



Courtesy Pratt and Whitney Aircraft

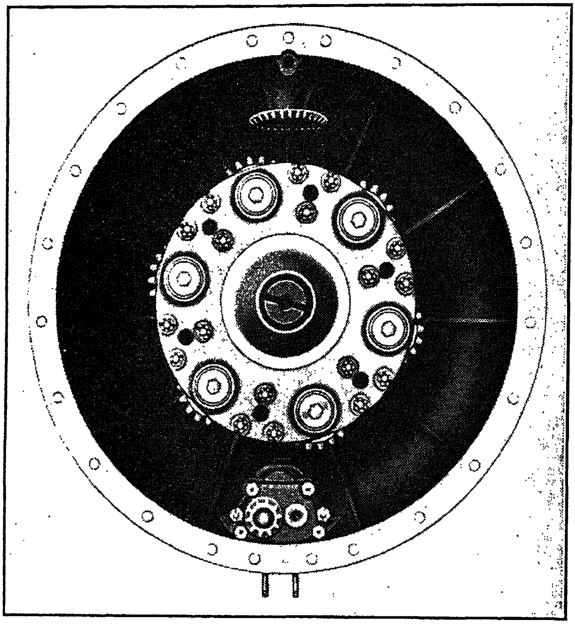
FIG. 51. Cutaway view of a 14-cylinder double-row radial engine.



Courtesy Pratt and Whitney Aircraft

FIG. 52. Full front view of a 14-cylinder radial engine with geared propeller drive.

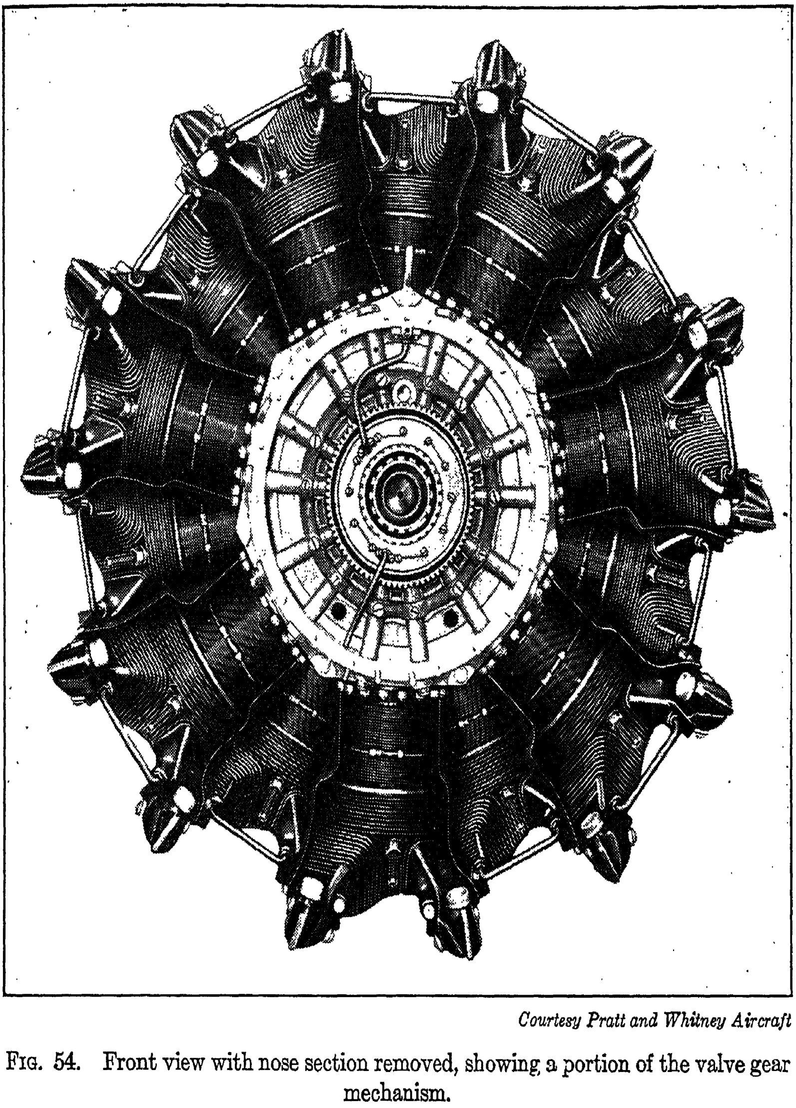
hole in the cylinder pad for receiving the cylinder barrel or skirt is usually tapered for a short distance so as to receive a synthetic rubber, oil seal ring installed around the cylinder skirt. The cylinders are secured in place with either studs and nuts or cap screws. The cylinder skirts of inverted and radial engines extend well into the crankcase so as to prevent oil in the crankcase from running down into the cylinders.



Courtesy Pratt and Whitney Aircraft

FIG. 53. Rear sectional view of the nose section, showing a portion of the reduction gear.

It is an interesting observation, and one of which engine designers take cognizance, that, if piston speed is held the same in geometrically similar engines, their volumetric efficiency, I.m.e.p., inlet air velocity, unit inertia stresses, and other characteristics will be the same. Of course, to maintain the same piston speeds it will be necessary for the smaller engine to turn up more rpm than the larger engine. The indicated horsepower of geometrically similar engines, running at the same piston speed, is proportional to the square of a lineal dimension of the engines. As an example, suppose that there are two geometrically similar engines. As we can take any comparable lineal dimensions, let us take their piston diameters which are, say, 2 and 3 in. The engine



Courtesy Pratt and Whitney Aircraft

Fig. 54. Front view with nose section removed, showing a portion of the valve gear mechanism.

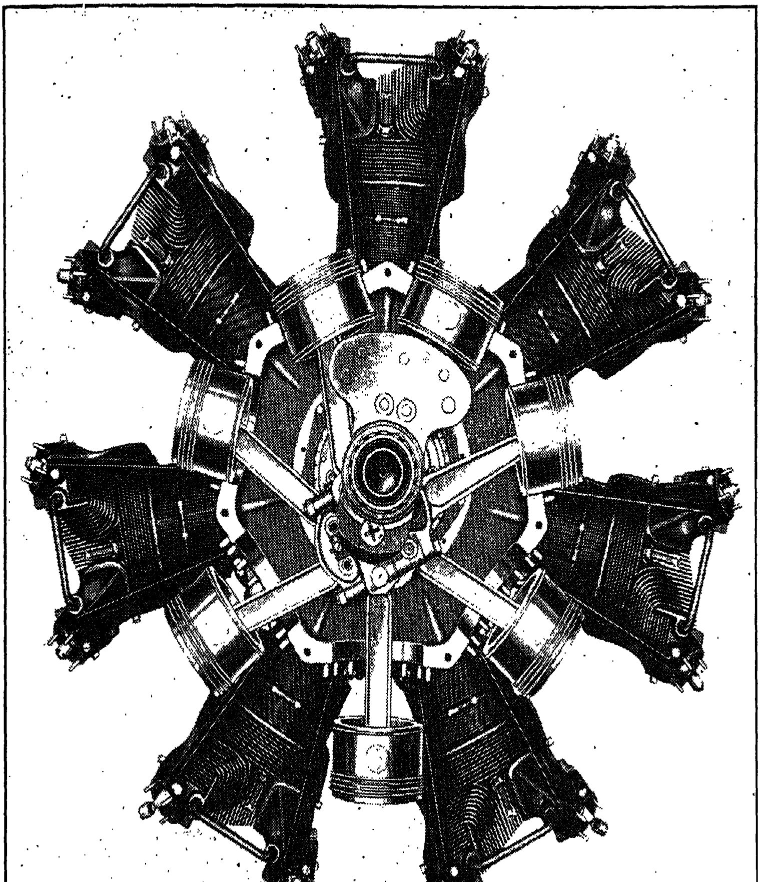
with the 3-in. diameter piston we know to develop an ihp of 300 hp at a piston speed of 2800 ft per min. If the ihp of each engine is proportional to the square of a lineal dimension, the ihp of the engine with the 2-in. diameter piston at 2800 ft piston speed will be:

$$\text{Ihp (2-in. piston engine)} = 300 \times \frac{(2)^2}{(3)^2} = 133 \text{ hp}$$

The ihp of geometrically similar engines with the same piston speed decreases as the square of a lineal dimension, but the weight of geometrically similar engines decreases as the cube of a lineal dimension. This results in the weight decreasing at a faster rate than the horsepower and hence a lower unit weight per ihp as the engine becomes smaller. A conclusion which might be drawn from this is that it would be better to have a large number of small cylinders than a small number of large cylinders, where unit weight per horsepower is a consideration. This does not hold true, however, when the cylinder size decreases and number increases beyond a point where the weight of the accessories and other engine components, which do not decrease in weight with the cylinders, overbalances the weight saving of the cylinders.

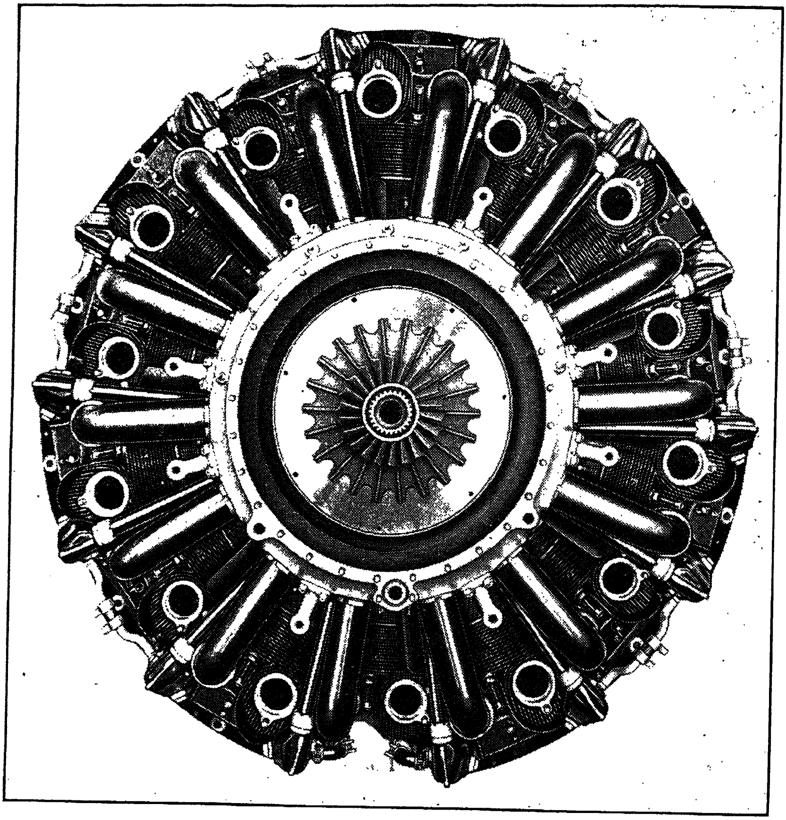
Fastenings. There are three common methods of fastening parts together. They are the bolt, the stud, and the cap screw. Of these three the bolt is the most common. But, to tighten and loosen a bolt it is necessary to be able to get at both the bolt head and the nut unless the shank and bolt hole are so shaped as to prevent turning of the bolt. There are many places in the engine where it would be either impossible or cumbersome to get a wrench on both the bolt head and nut. In such places there is the alternative of using either a cap screw or stud. The installation and removal of steel threaded screws in aluminum alloy soon wears out the aluminum alloy threads. The only alternative left, then, for aluminum alloy parts is to use a stud which is left in place once it is screwed into the aluminum alloy part.

Threads are designated by their diameter, the number of threads per inch, and their form. There are several thread standards and thread forms. The most common standard threads used in aircraft engines are the American National Coarse (NC) and National Fine (NF). These standards agree with others such as S. A. E. and U. S. Standard. The form of the American National thread is that of a V with the tips of the V cut off. Such a thread has sharp inner corners and will fatigue under continued reverse loading much sooner than a thread which has well-rounded corners. It is believed that eventually the standard thread form for aircraft engine fastenings will be similar to that of the Whitworth thread, which is a V-type thread with the tips of the V



Courtesy Pratt and Whitney Aircraft

FIG. 55. Front view, showing front bank of cylinders and front portion of crankcase removed.



Courtesy Pratt and Whitney Aircraft

FIG. 56. Rear view with accessory section removed, showing supercharger impeller.

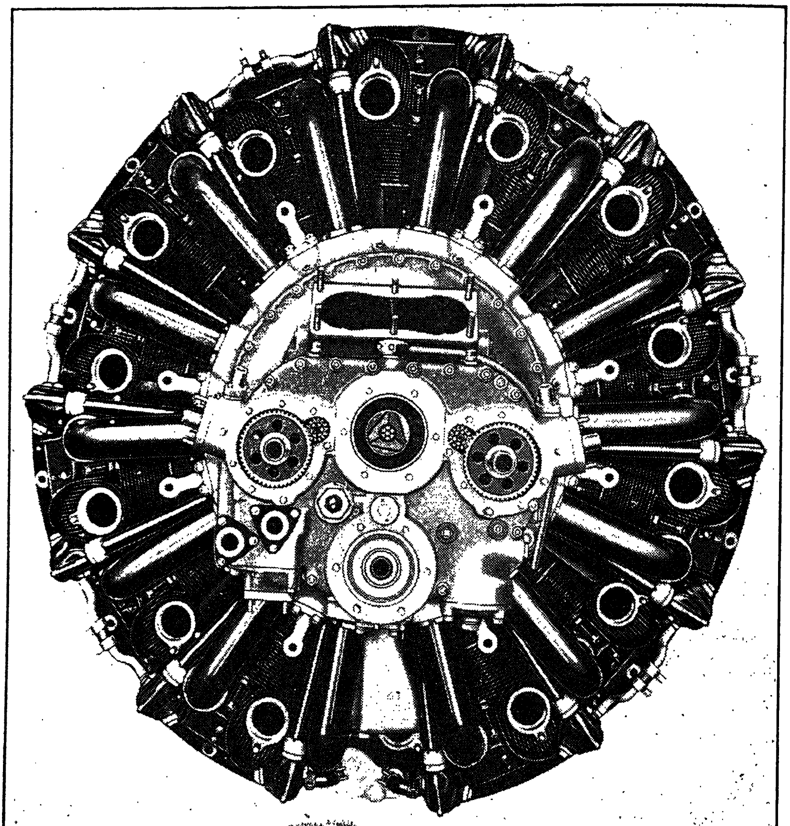
rounded off in generous radii rather than cut off parallel to the run of the threads.

Studs are generally made with coarse threads on one end and fine threads on the other. The coarse threads screw into the part into which they are to stay. To prevent the stud from backing out, the stud threads must be slightly larger in diameter than the female threads so as to give a tight fit. Litharge and glycerine, Glyptal, and other compounds are sometimes used on stud threads to glue them in place as an added precaution against backing out. Several different kinds of tools are in use for screwing the studs into place or driving the studs, as it is known, without injuring the protruding threads. One simple method is to screw two nuts onto the protruding threads, lock them by tightening against each other, and then use the nuts as if they were a bolt head to screw the stud into place or remove it.

Much trouble is sometimes experienced in removing studs which have been broken off, not leaving enough stud protruding to obtain a firm grip. A screw extractor is about the only tool for removing such a stud. The screw extractor is similar to a lefthanded wood screw with a square-tipped shank to which a tap wrench may be attached. To remove the stud, first center-punch the stud and then drill it with a drill of proper size for the screw extractor selected. If there is any doubt as to whether the hole can be drilled by hand, concentric with the stud, a jig should be used to hold a drill bushing concentric with the stud. Care must be taken not to drill all the way through the stud if drill chips might get into the engine interior. With the hole drilled in the stud, the screw extractor is inserted in the hole and the stud backed out. If difficulty is encountered in extracting the stud, heat from a blowtorch or welding torch will expand the stud hole more than the stud and make extraction easier. Every precaution must be taken against fire if the engine is still installed. The replacement stud must be oversized because the stud hole has been made larger by the original stud.

If an accurate drill jig is available and no harm will be done by drill chips falling out the rear of the stud hole, a broken stud may be removed by selecting a drill the same diameter as the root diameter of the stud threads. If such procedure is used the stud-hole threads should be retapped after the stud is removed and the proper oversized stud used as a replacement.

When stud-hole threads are mutilated during stud extraction the Aero-Thread stud is a handy replacement. If desired, the broken stud may be drilled out when tap-drilling for the Aero-Thread stud, since the Aero tap drill size is larger than the root diameter of the original stud threads. The installation of an Aero-Thread stud is illustrated in



Courtesy Pratt and Whitney Aircraft

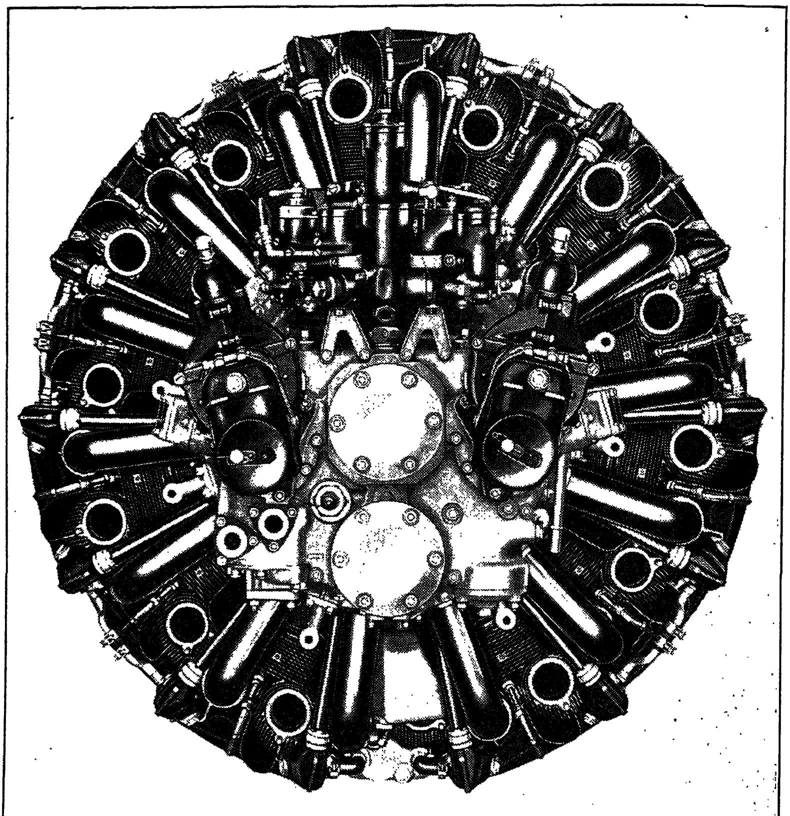
Fig. 57: Rear view with accessory section in place.

Fig. 63. After the stud hole is tap-drilled to the proper size, it is tapped with a special Aero tap. The Aero-Thread insert, which resembles a coil spring, is then screwed into place with a special tool. The Aero-Thread insert acts as the female threads which receive the Aero stud. The stud threads bear against the insert and not against the crankcase in this instance. Such an arrangement makes it possible to use cap screws in aluminum alloy and magnesium alloy parts. If inserts become worn they may be replaced. The generous radii of the Aero-Thread stud threads give it a fatigue strength of about one and one-half times that of the NC thread.

To prevent nuts from coming loose with the continued vibration during engine operation it is necessary to provide some means of locking them in place. Lock washers and cotter pins are the most common types of locking devices. Installation and removal of nuts with lock washers mutilate surfaces against which they bear, especially when the surfaces are relatively soft material, such as aluminum alloy. Cotter pins require that the slots between the castles of the castellated nut line up with the hole in the bolt. This is not desirable when tightening to specified torques. However, cotter pins and safety wire are used in many places on the engine. Never back up on the castellated nut to align its slots with the bolt hole. New cotter pins or safety wire should be used each time a nut is installed.

Several types of locking devices and self-locking nuts have been developed which are well adapted for aircraft engine use. The self-locking principle of the two nuts shown in Figs. 65 and 66 is that they maintain a constant pressure on the load-carrying side of the nut threads, thereby eliminating any axial play, regardless of the force or lack of force against the base of the nut. It is the axial play of a nut that allows it to back off on the male threads. The nut of Fig. 66 depends upon an elastic fiber washer made integral with the nut to maintain the force on the load-carrying side of the threads. The nut of Fig. 65 depends upon a threaded collar above the main section of the nut and attached to it by a spring bellows. The threads of the collar are out of lead with those of the nut and thereby maintain a tension on the spring bellows when the nut is screwed onto the male thread.

Self-locking nuts are used in many external locations on the aircraft engine. They may be removed and installed a number of times without losing their locking effectiveness. They are not used internally where they cannot be inspected. The limitations on self-locking nuts as prescribed by the Civil Air Regulations are:



Courtesy Pratt and Whitney Aircraft

FIG. 58. Rear view with magnetos, carburetor, and accessory cover plates in place.

The following self-locking nuts are acceptable for use on certificated aircraft subject to the restrictions noted. This list is compiled from data on file with the Civil Aeronautics Administration and may be expanded or revised upon receipt and approval of additional information.

Manufacturer	*Style*	*Material*	*Notes*
Boots Aircraft Nut Co.	Bellows	Steel or Al. Alloy	1, 3, 4
Boots Aircraft Nut Co.	Wing	Steel or Al. Alloy	1, 3, 4
Elastic Stop Nut Corp.	"Hytemp"	Steel	1, 3, 4
Elastic Stop Nut Corp.	Fibre Insert	Steel or Al. Alloy	1, 2
The Palnut Co.	"Palnut"	Steel	5
Tinnerman Products, Inc.	"Speed Nuts"	Steel	6

NOTE 1. The following general restrictions apply to the use of these nuts:

(a) Material should conform with Army or Navy specifications.

(b) They should not be used at joints which subject the bolt or nut to rotation.

(c) Bolts, both drilled for cotters and undrilled, having rounded or chamfered ends should be of such length that at least the full round or chamfer extends through the nuts, except that 3/16 in. and 1/4 in. diameter bolts drilled for cotter pins should extend at least two full threads through the nuts. Flat end bolts, both drilled and undrilled, should extend 1/32 in. through the nuts, except that 3/16 in. and 1/4 in. diameter drilled bolts or screws should extend at least two full threads through the nuts.

(d) They should be called out on the pertinent drawings submitted to the Administrator.

NOTE 2. Nuts of this type should not be used where subject to temperatures in excess of 250°F.

NOTE 3. Nuts of this type should not be used for primary structural connections in the following specific applications:

(a) They should not be used to attach wing panels, fins, and stabilizers.

(b) They should not be used in the control system, including surfaces, hinges, and bracket attachments thereof.

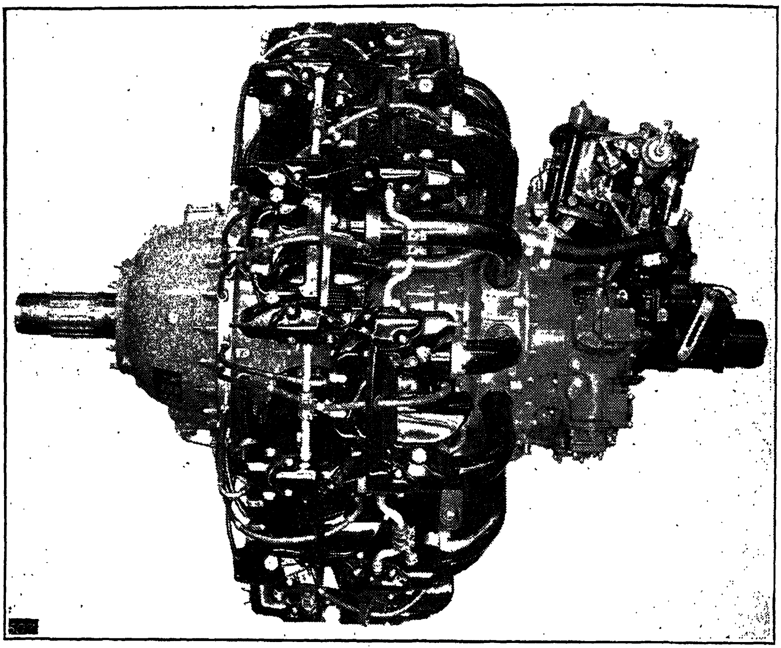
(c) They should not be used to attach exhaust manifolds and similar items where the temperature may exceed 450°F.

NOTE 4. They should not be used where less than three nuts are used to secure a main structural member or other primary application.

NOTE 5. These items may be used only in non-structural and secondary structural parts of airplanes and on externally visible engine bolts.

NOTE 6. Nuts of this type may be used only in non-structural and secondary structural parts of airplanes.

The " Palnut " illustrated in Fig. 67 is used on many aircraft engines for locking external nuts in place. It is a single-thread locknut pressed out of sheet steel, hardened and tempered after forming. The working portion consists of resilient spring jaws that grip the root of the bolt or stud threads all around and also maintain a spring tension against the regular nut.



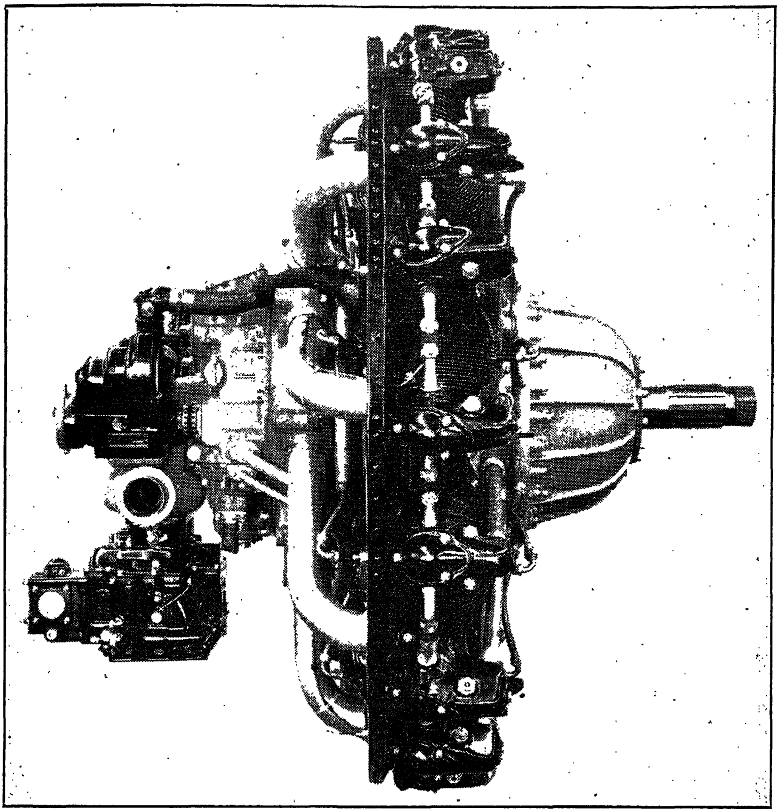
Courtesy Pratt and Whitney Aircraft

FIG. 59. Full side view of 14-cylinder double-row radial air-cooled engine.

The " Palnut " is applied to the bolt on top of the regular nut, after the regular nut has been tightened. It turns on easily with the fingers. After it has come up against the regular nut it is given from a quarter- to a third-turn with a wrench to lock it in place. Never use " Palnuts " a second time.

The majority of bolt and stud failures are caused by improper tightening and unequal pressure on the seating faces of the bolt heads or nuts. If the bolt head seating face, nut seating face, and faces against which they seat are not square with the axis of the bolt or stud, all the pressure or a greater portion of the pressure will be exerted on only one side of the bolt head or nut. This concentration of stress on one side

will naturally start a failure if the unit strength of the material is exceeded. In critical positions such as cylinder hold-down studs, washers with one face shaped spherically are used to eliminate the possibility of unequal loading on the nut seating face. The spherical face of the washer fits into a spherical countersink in the cylinder-attaching



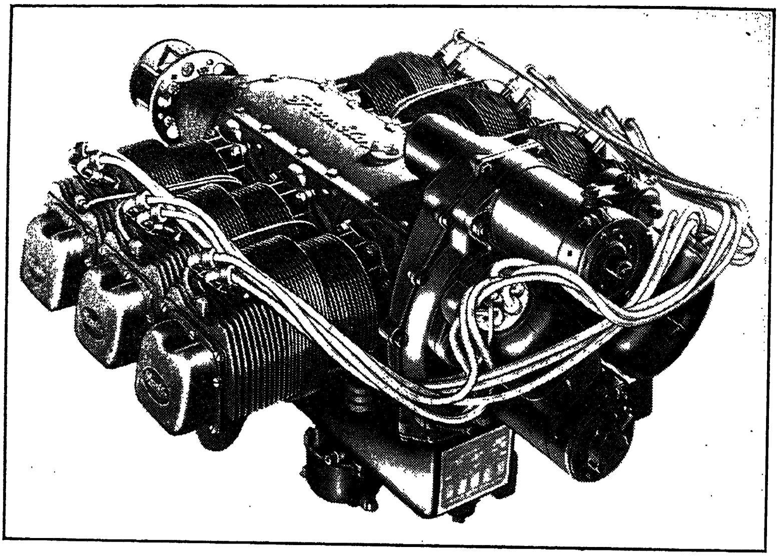
Courtesy Pratt and Whitney Aircraft

Fig. 60. Full side view of 9-cylinder single-row radial air-cooled engine.

This allows the spherical face of the washer to move in its spherical seat, thereby permitting the flat face of the washer always to coincide with the seating face of the stud nut.

Whether the force exerted upon a bolt head or nut after it has been tightened ever exceeds the force exerted upon it by tightening is problematical. In Fig. 68 (*a*), suppose that a portion of the cap screw shank is a spring. The cap screw is tightened so that it exerts a force *A*-*A*

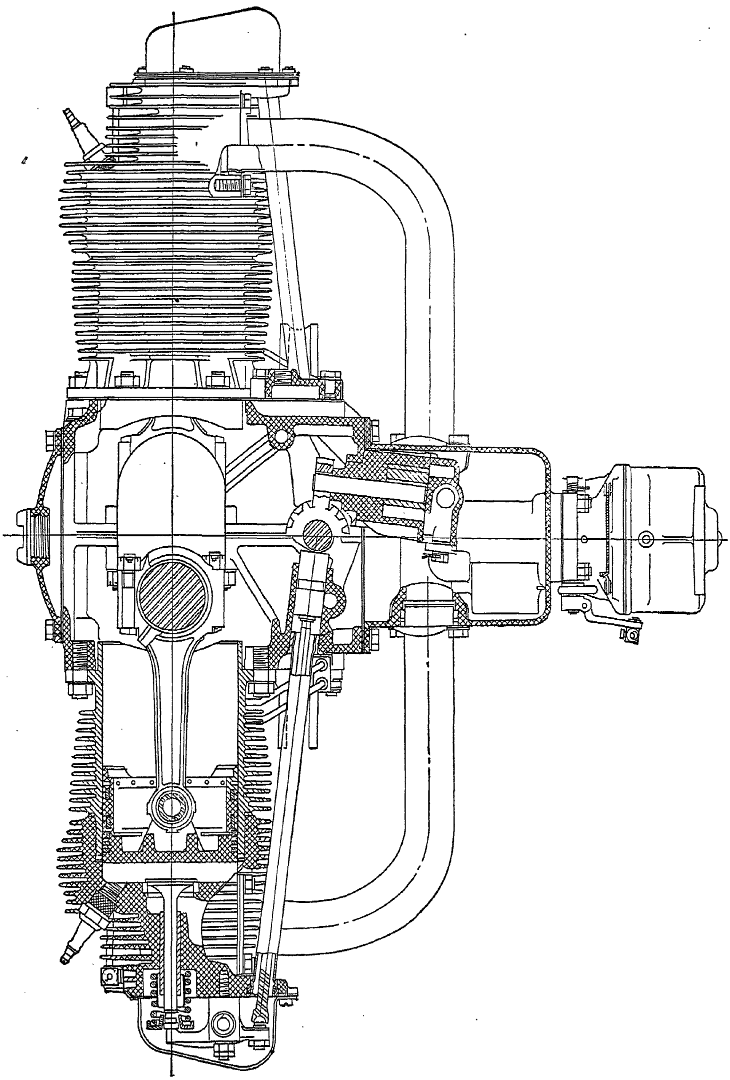
against the rigid flange. If the force *A-A* of the cap screw head against the flange is, say, 1000 lb, any force (*F*) on the flange up to 1000 lb will not exert any more pressure against the head of the cap screw. In Fig. 68 (*b*), suppose that the cap screw is rigid and the flange has springs on either side. The cap screw is tightened to exert a force *A-A* on the springs. Any force (*F*) on the flange now increases the force against the cap screw head. In actual practice both the cap screw and the flange have some springiness and it is difficult to determine what forces would be necessary to put an additional force on the cap screw head after it had been tightened to a certain force.



Courtesy Aircooled Motors Corporation

FIG. 61. Three-quarter view of a 6-cylinder opposed air-cooled engine.

Through experience certain values for tightening fastenings have been established. To ascertain the tightness of a bolt, its elongation after tightening may be measured. In this instance it is specified that the bolt has been drawn to the proper tightness when it has elongated so many thousandths of an inch. The most common method of measuring the tightness of a nut is to measure the force or torque applied in tightening it. For doing this there are many torque wrenches on the market. Torque is, of course, measured as the number of pounds pull at a certain distance from the center of the nut. A pull of 1 lb on a wrench handle at a distance of 1 ft from the center of the nut would



Courtesy Aircooled Motors Corporation

FIG. 62. Cutaway diagram of a 6-cylinder opposed, air-cooled, 120-hp engine.

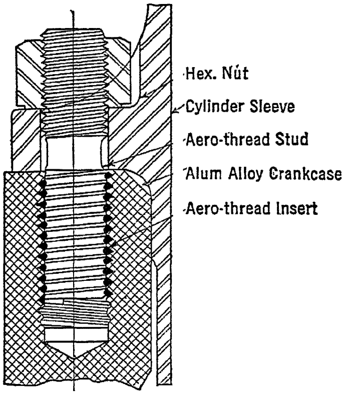
TABLE I

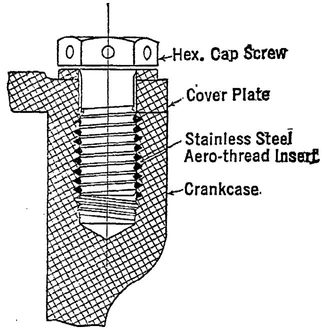
TIGHTENING TORQUE VALUES

(Special cases and exceptions to these values may exist.)

STANDARD STUDS, BOLTS, SCREWS, AND CAP SCREWS

Name	Size of Thread Nut End	Minimum Diameter of Thread Root or Neck (In.)	Minimum Rockwell Hardness	Torque Values: Driving Stud, Minimum (In.-Lb)	Torque Values: Driving Stud, Maximum (In.-Lb)	Torque Values: Tightening Nut, Screw, or Cap Screw, Minimum (In.-Lb)	Torque Values: Tightening Nut, Screw, or Cap Screw, Maximum (In.-Lb)
Button head screw	10–32	0.1467	B-50			20	25
Button head screw	12–24	0.1585	B-50			25	30
Studs, bolts, screws and cap screws	10–32	0.1467	C-19			35	40
"	12–24	0.1585	C-19			45	50
"	1/4–28	0.180	C-26	50	70	80	85
"	5/16–24	0.229	C-26	100	150	160	175
"	3/8–24	0.285	C-26	200	275	225	250
"	7/16–20	0.331	C-26	300	425	350	375
"	1/2–20	0.387	C-26	500	700	550	600
"	9/16–18	0.436	C-26	750	975	825	875
"	5/8–18	0.493	C-26	1100	1400	1125	1200
STANDARD PRACTICES FOR SPECIAL APPLICATIONS							
Cyl. hold-down stud	3/8–24	0.313	C-32	325	450	350	375
Cyl. hold-down cap screw	7/16–20	0.330	C-26			375	400
Cyl. hold-down stud	7/16–20	0.331	C-32	400	550	425	450
Rocker hub bolt	7/16–20	0.371	C-32			250	325
Rocker hub bolt	15/32–20	0.400	C-19			250	325
Rocker hub bolt	9/16–18	0.488	C-26			300	375
Spark plug	18 mm					450	500

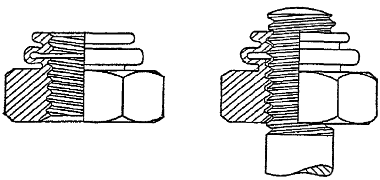




Courtesy Aircraft Screw Products Company

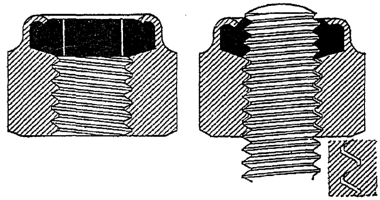
FIG. 63. Aero-Thread cylinder flange stud in a forged aluminum alloy crankcase.

FIG. 64. Aero-Thread aluminum alloy cap screw in an aluminum alloy casting.



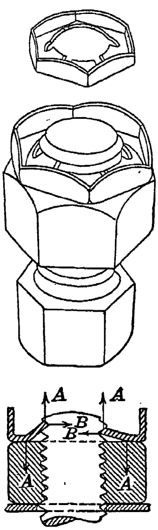
Courtesy Boots Aircraft Nut Corporation

FIG. 65. The Boots self-locking nut.



Courtesy Elastic Stop Nut Corporation

FIG. 66. The Elastic Stop Nut self-locking nut.



Courtesy The Palnut Company

FIG. 67. The Palnut locking device.

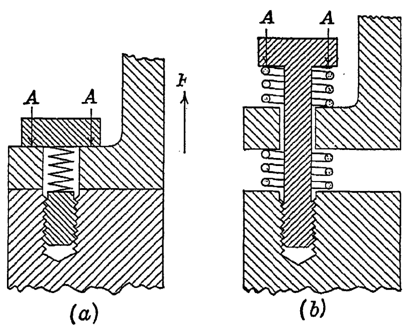


FIG. 68. Cap screw securing flange in place. Springs represent the elasticity of (*a*) the cap screw and (*b*) the flange.

be a torque of 1 lb-ft or 12 lb-in. Erroneously torque is often expressed in foot-pounds and inch-pounds rather than in pound-feet and pound-inches. Table I is a table of tightening torque values as established by the Wright Aeronautical Corporation.

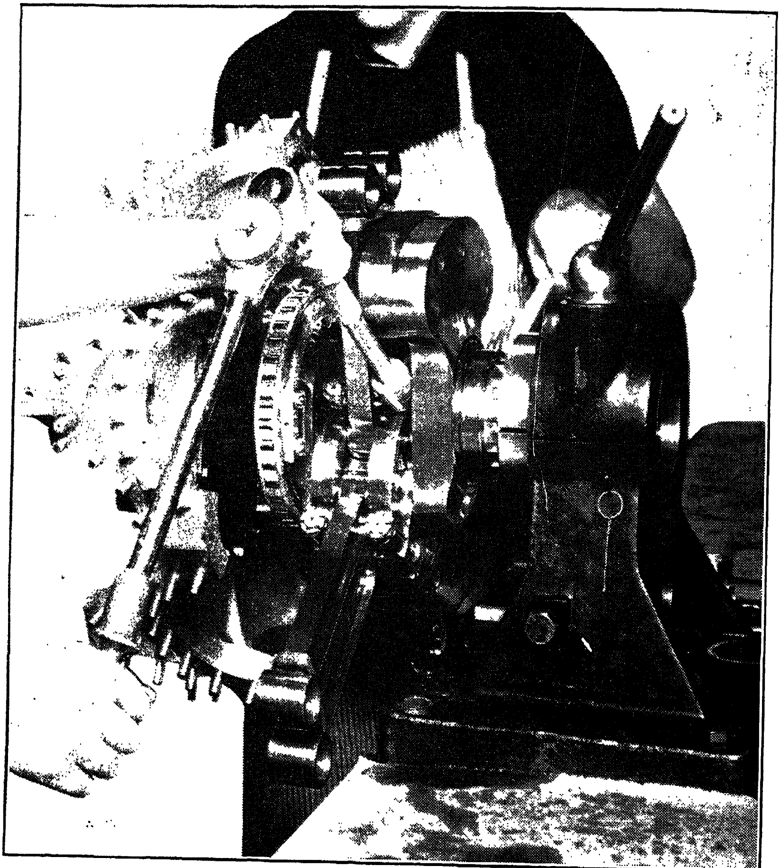


FIG. 69. Using a torque wrench for tightening a master rod cap screw.

The accuracy of a torque wrench may be checked by clamping the driving square of the wrench in a vise so that the handle stands straight out. Add weights of known value to the handle and check the readings against the product of the weights (in pounds) and the distance from the handle to the center of the driving square (in inches or feet, depending upon whether the indicator reads in pound-inches or pound-feet).

Some torque wrenches will show different indications, depending upon the method of gripping the handle. The wrench manufacturer's instructions should be adhered to in the use of the wrench. When tightening with a torque wrench, the wrench should be held stationary for several seconds after the proper value is reached. This takes care of the lag in the nut movement.

CHAPTER IV

FUELS, FUEL SYSTEMS, AND REFUELING

There are a number of gaseous, liquid, and even solid substances which may be used as a fuel for internal combustion engines. Gasoline, a refined product of petroleum, is the principal fuel used in aircraft engines in this country, principally because of the plentifulness of petroleum.

Petroleum, or crude oil, is a mineral oil consisting of a solution of various hydrocarbons and small amounts of sulphur, nitrogen, and oxygen. It is classified according to its composition as paraffin base, asphaltum base, or mixed base crude. In all fuels the two basic combustible elements are carbon and hydrogen, encountered either separately or in combinations called hydrocarbons. The general chemical formula for hydrocarbons is C_nH_m. In a crude oil there are a very great number of these various hydrocarbons combined in different proportions and different arrangements of molecular structure.

Refining Processes. The various hydrocarbons contained in a crude oil have different boiling points. This permits a process of refining known as fractional distillation. The lightest fractions, which are those with the lowest boiling point, are driven off at comparatively low temperatures. As the temperature is increased the fractions with increasingly higher boiling points are driven off. The general groups into which the various fractions are usually separated are listed below in the order in which they boil off.

1. Uncondensable gases (methane and ethane).
2. Liquefiable gases (propane and butane).
3. Gasoline.
4. Naphthas and fuel oils.
5. Kerosene and fuel oils.
6. Lubricating oils.
7. Asphalt, road oils, and petroleum coke.

Besides fractional distillation, which is the simplest refining process, there are several other processes for obtaining a desired quality of fuel from petroleum. *Cracking* is a process for obtaining more of the lighter fractions out of the crude oil than were originally present. The

cracking process breaks the heavier hydrocarbons up into lighter ones by literally splitting the molecules of the heavy hydrocarbons. The process is based on the principle that the heavy hydrocarbons are unstable compounds when heated above a certain critical temperature. Gasoline obtained by the cracking process is superior in volatility and *high antiknock value to gasoline obtained by straight distillation.* After the cracking process is completed fractional distillation must be resorted to for the segregation of the various fractions.

The *polymerization* process is a rather new process which is being used extensively now for producing gasoline. In a general way it may be said that polymerization is the reverse of cracking. Under proper conditions the molecules of the light fractions may be made to combine with one another to form heavier molecules which are liquid under atmospheric conditions. Gasoline obtained by this process is very high in antiknock quality. The amount of gasoline which can be obtained by this process from a unit quantity of crude oil is obviously limited by the amount of the light fractions obtained from the distillation and cracking processes.

Iso-octane is a hydrocarbon which boils at about 212°F, and which has such a high antiknock value that it is used as the standard in antiknock testing for motor fuel. It occurs only in low concentrations in crude oils, but may be rather easily made from iso-butane, one of the constituents of refinery fuel gas.

Since iso-octane is a saturated compound it is very stable chemically; this makes it valuable as a component of aviation fuels. Commercial iso-octane has a boiling range of about 210 to 240°F, which necessitates blending with some other gasoline cuts in order to comply with volatility specifications. However, it is possible to make a 100 octane rating aviation fuel with only a very small amount of tetraethyl lead added to a blended iso-octane fuel.

Quality of Gasoline. There are four properties which determine the quality of an aviation gasoline.

1. Volatility.
2. Purity.
3. Antiknock rating.
4. Heating value.

Volatility is commonly expressed in terms of distillation range. The volatility of a gasoline governs the ease of starting, the possibility of vapor locks, the possibility of lubricating oil dilution, and the rate of engine acceleration. The temperature at which the first 10 per cent of the fuel will boil off is a measure of the ease of starting. For starting

there must be a sufficient fraction of the gasoline which is volatile enough to supply enough fuel vapor to produce a combustible mixture. On the other hand the fuel must not be so volatile as to permit it to boil in the fuel lines and cause "vapor locks," because this would obstruct the flow of fuel. The danger of vapor lock is increased as the aircraft gains altitude since the boiling temperature of the fuel is reduced with the reduction in atmospheric pressure.

The ease of acceleration of the engine is indicated by the temperature at which 50 per cent of the gasoline is boiled off. The temperature at which 90 per cent is boiled off indicates whether all the fuel can be volatilized or whether some must remain unburned. Fuel which does not completely volatilize has a tendency toward smoky combustion. The heavy ends of a gasoline which are imperfectly burned in the cylinder will leak past the piston rings and dissolve in the lubricating oil, thus causing dilution of the oil.

Purity. Freedom from water, dirt, or other foreign matter is, of course, essential in an aviation fuel. Any corrosive tendency of the fuel, or of impurities which it may contain, should also be avoided. Sulphur is an impurity which, if not removed from gasoline, has a corrosive action on the parts of the fuel system and engine, especially those parts made of copper or brass. Gum is an objectionable product sometimes found in gasolines. It has a tendency to deposit in the fuel system and on valve guides. Excessive amounts of gum will cause such troubles as sticking valves and plugging or restriction of fuel passages. Gum is caused by a process of slow oxidation. It is general practice for the oil refiners to put an inhibitor in gasoline to prevent gum formation while in storage.

Antiknock Rating. Antiknock value is a term used to describe the detonation a fuel causes in the engine cylinders. The value is arrived at by comparing the fuel with arbitrarily chosen standard fuels, since there is no absolute standard with which to make a comparison. The standard fuels are iso-octane, which has an antiknock value considerably higher than most gasolines, and normal heptane, which is a severe "knocker" as compared with gasoline. These fuels are mixed together in different percentages until the antiknock value of the mixture equals that of the fuel to be rated. The percentage of iso-octane in the matching mixture is taken as the "octane member" of the fuel.

Detonation, or engine knock, has been found to be related to the temperature-time-ignition characteristic of the fuel used in the engine. A fuel which has a low self-ignition temperature, and which at the same time requires a relatively short time after the temperature has

been reached for the ignition to occur, will have a great tendency to detonate. On the other hand, a fuel which has a high self-ignition temperature, or which requires a relatively long time for ignition to occur after the temperature has been reached, will not have so great a tendency to detonate. Cracked gasolines, because of their temperature-time-ignition characteristics, have less tendency to detonate than straight distillation gasolines.

In addition to the natural knock-suppressing characteristic of cracked distillates, a number of metallic compounds have been found which, when dissolved in low concentration in the fuel, will improve the antiknock quality. Lead tetraethyl is a very successful compound for commercial application.

By taking advantage of the new high antiknock fuels, it has been possible for engine designers to use much higher compression ratios, thus improving the utilization of the power available in a gallon of gasoline and increasing the power output per pound of engine weight.

A frequent but erroneous belief is that more power can be obtained from a given engine by using a higher-octane fuel than the minimum required to eliminate detonation. If an engine is free from detonation when using an 80-octane fuel, nothing would be gained by using a 90-octane fuel unless mechanical changes were made to increase the compression ratio.

Heating Value. The heat liberated when a unit weight of fuel is burned completely is known variously as the heat of combustion, heat content, and calorific value. In the English system, it is measured in Btu's per pound of fuel. Since the output of an engine is dependent upon the heat received, it follows that the output depends upon the heat content of the fuel supplied and the percentage of the supplied fuel that burns completely.

The heat content of different hydrocarbons varies, of course. However, it can be assumed that gasoline has a formula equivalent to octane, C_8H_{18}, which is a fair average. The heating value of octane is approximately 19,000 Btu per lb.

Combustion of Fuel. All hydrocarbons with the general chemical formula C_nH_m burn in the presence of sufficient oxygen to form carbon dioxide and water. Assuming that aviation gasoline has the average equivalent composition of octane, C_8H_{18}, it will require 3.509 lb of oxygen to burn completely 1 lb of gasoline. Since 1 lb of air contains only approximately 0.23 lb of oxygen, it will be necessary to have 15.25 lb of air to burn completely 1 lb of gasoline or, stated another way, 0.0665 lb of gasoline may be completely burned by the oxygen in 1 lb of air. This ratio of fuel to air is known as the fuel-air mixture

ratio. The ratio of 0.0665 lb of fuel per pound of air is known as the chemically correct fuel-air ratio.

When two substances react chemically with each other the reaction does not always proceed to the point where one of the substances is completely consumed. Before this happens, an equilibrium condition is reached in which not only the products of reaction are present, but also appreciable amounts of the original products, and sometimes intermediate compounds. The conditions of equilibrium depend upon the proportions of the original products and the temperature and pressure

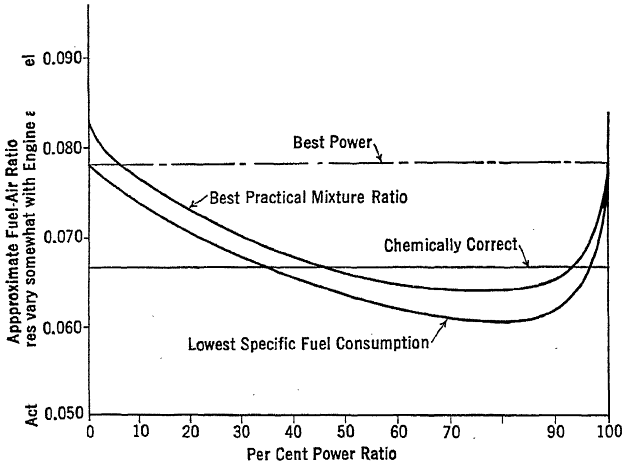


FIG. 70. Fuel-air mixture ratio vs. per cent of power ratio.

after the reaction has taken place. In reactions where heat is liberated it may be said, in general, that the reaction is less complete at high temperatures than at low temperatures. Because of this equilibrium condition it is necessary to furnish more fuel to the fuel-air mixture than the chemically correct ratio. Under actual working conditions it is necessary to have a fuel-air mixture in the neighborhood of 0.080. This is known as the best power mixture.

A fuel-air mixture which has less fuel than enough to consume completely all the oxygen is called a " lean " mixture. One that has more than enough fuel is called a " rich " mixture.

There are limits between which the mixture must be or it will not burn. An excessively lean mixture will not burn at all or it will burn so slowly that combustion is not complete at the end of the exhaust stroke. The flame lingers in the cylinder and ignites the contents of the intake manifold, causing an explosion known as *backfiring.*

Excessively rich mixtures are also slow burning. Since there is more fuel than enough to burn all the oxygen, single atoms of oxygen combine with single atoms of carbon (normally the combination is 2 oxygen to 1 carbon) to form carbon monoxide, which is a very poisonous gas. A richer mixture than the best power mixture is a waste of fuel, except when it is used to control detonation or assist in cooling.

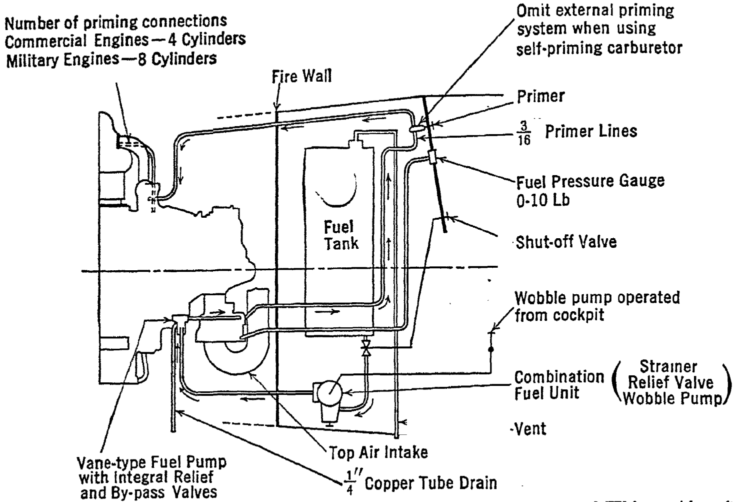
In a normal engine, the best power occurs at the same mixture ratio (best power mixture) at all speeds and throttle settings (Fig. 70). The mixture for lowest specific fuel consumption is leaner than that for best power, but it becomes gradually richer as power is reduced, finally coinciding with that for best power. The mixture for the lowest fuel consumption is near that at which irregular running or backfiring will occur. Hence, the best practical mixture is slightly richer than the mixture for lowest fuel consumption, except that at take-off power the best power mixture is required.

FUEL SYSTEMS

The function of the fuel system is to provide the engine with an adequate continuous supply of clean fuel under varying conditions of demand. To perform this function many different fuel system arrangements are in use. Each arrangement should be designed to accomplish the function in the simplest and most direct manner consistent with the design of the aircraft. Consideration must be given to the effects of acceleration, to an auxiliary means of pumping in the event that the main pumping system fails, to means of preventing vapor locks in the lines, to safety devices in the event of line or fitting failures, and to many other things conducive to a system which will function properly and offer the greatest amount of safety under all conditions of flight and probable emergency.

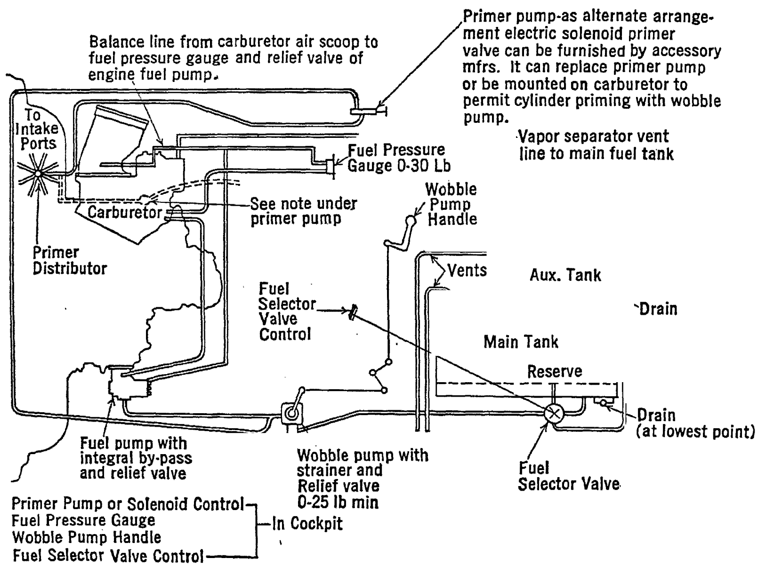
Fuel Pumps. The simplest type of fuel system would consist merely of a tank located above the carburetor and a line connecting it with the carburetor. In aircraft design, though, the tanks cannot always be located above the carburetor and it becomes necessary to provide a fuel pump. Earlier types of gear pumps were not entirely satisfactory because they wore rapidly and had very poor priming ability. The vane-type pump, illustrated in Fig. 74, is now almost universally used.

To maintain a constant pressure at the carburetor it is necessary to provide a relief valve on the pressure side of the fuel pump which will by-pass excessive fuel, either back to the inlet side of the pump or to the fuel storage tanks. Later types of pumps have the relief valve incorporated in the pump itself. By enclosing the relief valve spring



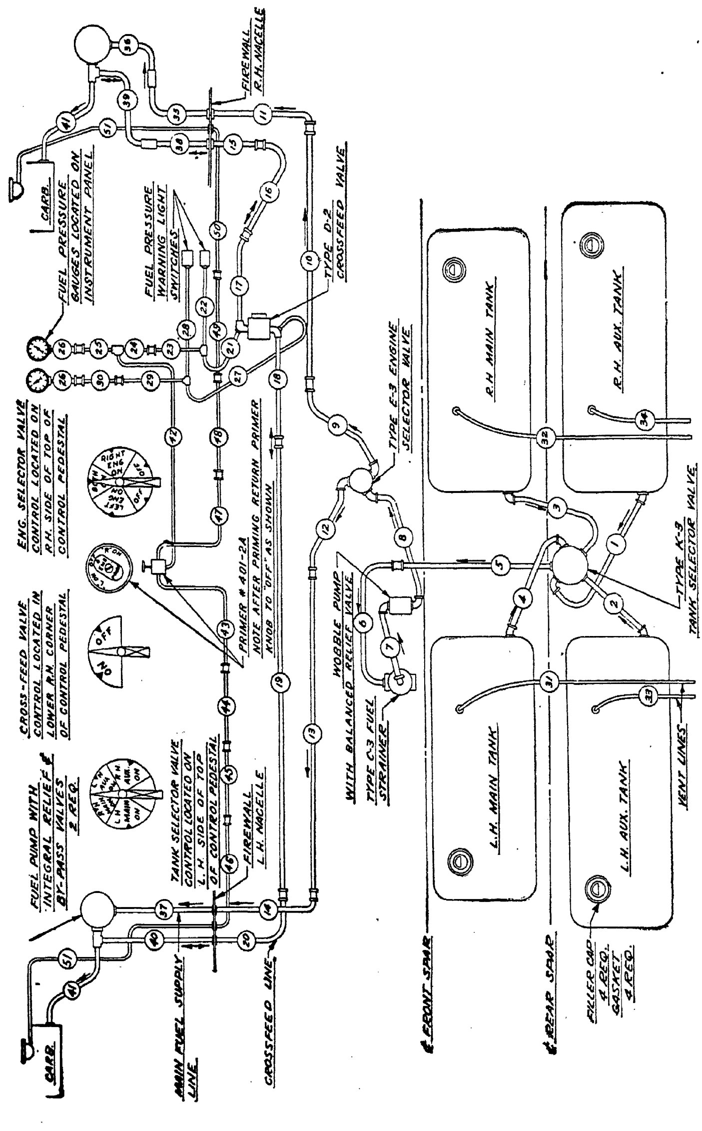
Courtesy Pratt and Whitney Aircraft

FIG. 71. Typical fuel system for a single-engine installation using updraft float-type carburetor.



Courtesy Pratt and Whitney Aircraft

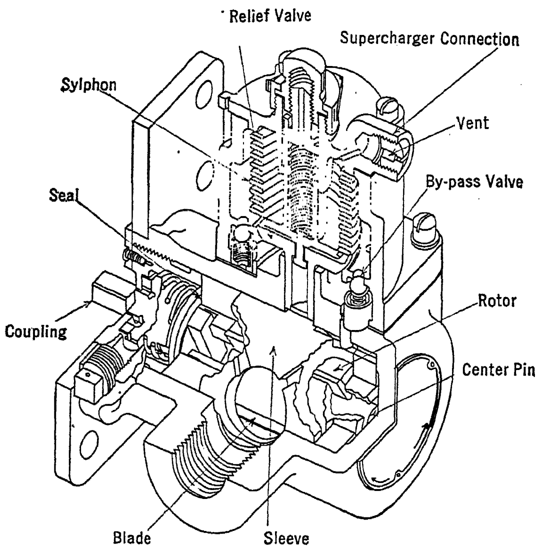
FIG. 72. Typical fuel system for a single-engine installation using downdraft injection carburetor.



Courtesy Douglas Aircraft Company

FIG. 73. Typical fuel system of a twin-engine aircraft.

in a metal bellows (sylphon), as illustrated in Fig. 74, and venting the inside of the bellows to the atmosphere, the pump will maintain a constant outlet pressure with varying inlet pressure. The relief valve allows excess fuel to pass from the discharge side of the pump back to the intake side when the discharge pressure exceeds the pressure setting of the relief valve spring. A variation in pressure in the compartment above the relief valve has no appreciable effect upon the pressure at which the valve relieves since any variation in pressure there acts about equally to close the valve and also to relieve the spring pressure on the valve through compression of the sylphon.



Courtesy Pump Engineering Service Corporation

Fig. 74. Fuel pump with sylphon-type relief valve.

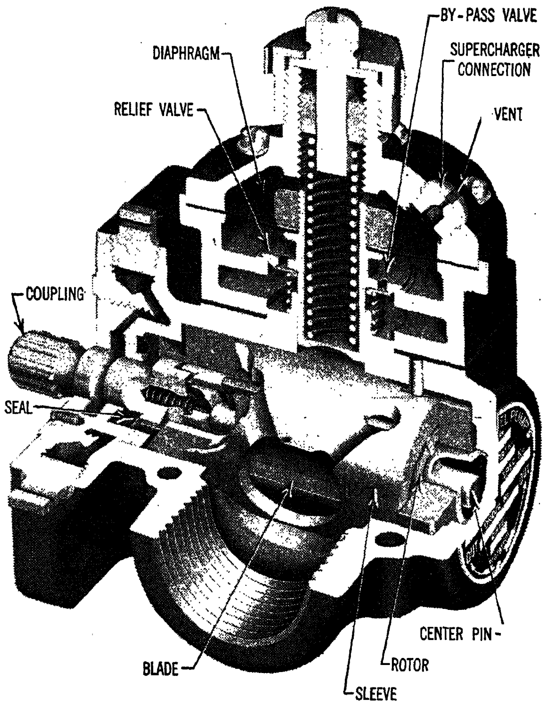
With the inner space of the sylphon vented to the atmosphere, the selected balance between atmospheric pressure and fuel pump discharge pressure is maintained constant. If it is desired to maintain a constant pressure difference between fuel pressure and manifold pressure or carburetor air scoop pressure, then the vent is connected respectively with the engine supercharger or the carburetor air scoop.

In the more recent fuel pumps the bronze sylphon is replaced with a diaphragm of rubber reinforced with fabric as illustrated in Fig. 75. The diaphragm provides greater flexibility and is not as readily subject to fatigue failure resulting from valve pulsation.

Fuel pumps must incorporate a by-pass valve which will allow fuel

to pass through the pump when it is inoperative. This is necessary so that the auxiliary pump can furnish fuel to the carburetor when the fuel pump is inoperative, such as before starting or in case of fuel pump failure. Operation of the by-pass valve of a diaphragm type pump is illustrated in Fig. 76.

The majority of fuel pumps are engine-driven. They are mounted directly onto the engine and are driven by either a square, tongue, or



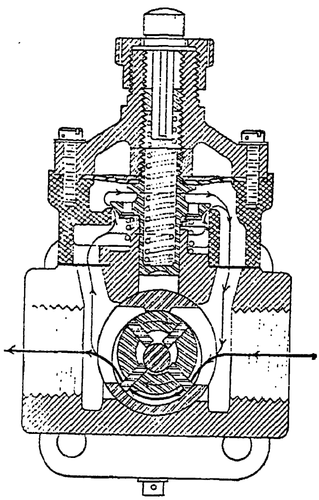
Courtesy Pump Engineering Service Corporation

FIG. 75. Fuel pump with diaphragm-type relief valve.

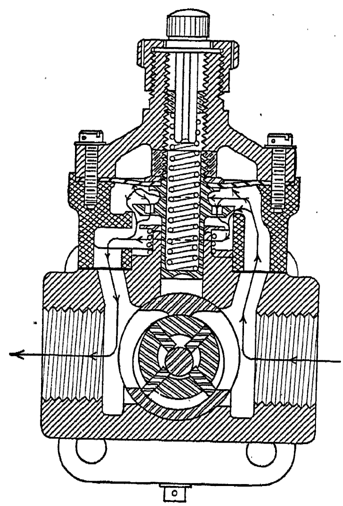
splined drive coupling, depending on the engine. The direction of rotation and the inlet and outlet ports of the pump are properly identified. All pumps do not rotate in the same direction and the proper direction of rotation must be ascertained before a pump is installed. When installing a pump, one should make certain that there is some end clearance at the drive shaft or else the shaft seal will be rendered ineffective.

Fuel pumps require very little maintenance between overhauls, which

generally correspond with engine overhaul. Some pumps require periodic lubrication of the drive shaft whereas in other installations lubrication is provided by the engine oil system. An oil drain connects to the pump body next to the mounting flange to carry away any excessive oil leakage from the engine. This line must be kept open. As a safety precaution the vent hole is very small (No. 80 drill) to minimize loss of pump suction in event of damage to the sylphon or diaphragm. Vent holes should never be enlarged. It is important that the vent hole be kept clear. An inspection should be made of the hole and the protecting screen cleaned at engine checks. Probably the easiest method of inspecting the hole is to insert into it the shank end of a No. 80 drill. Blocking of the vent hole will result in pressure fluctuations and a general increase in pressure with altitude.



(a)



(b)

Courtesy Pump Engineering Service Corporation

FIG. 76. Section through fuel pump with diaphragm-type relief valve, showing (*a*) normal fuel flow and function of relief valve and (*b*) how fuel is by-passed when pump is inoperative and hand pump is being used.

To adjust the fuel discharge pressure loosen the adjusting screw lock nut and turn the adjusting screw to increase or decrease the compression on the relief valve spring; this respectively increases and decreases the pressure. Some adjusting screws turn clockwise and others counterclockwise, to increase the compression. If the proper direction is not known it will have to be ascertained by trial and error. After adjustment is complete tighten the lock nut and safety in place.

Auxiliary Pumps. To provide some means of obtaining fuel pressure before the engine is started and as a safety precaution in the event of failure of the main fuel pump, an auxiliary pump is incorporated in the fuel system. The most common type of auxiliary pump is the hand-operated wobble pump whose principle of operation is illustrated in the diagram of Fig. 77. When the wobble pump is not in operation the flapper valves, which are closed only by gravity, are opened by the fuel flowing through the pump to the main pump. A pump that allows a free flow of fuel through it when not in operation is well adapted to series installation in the fuel supply line.

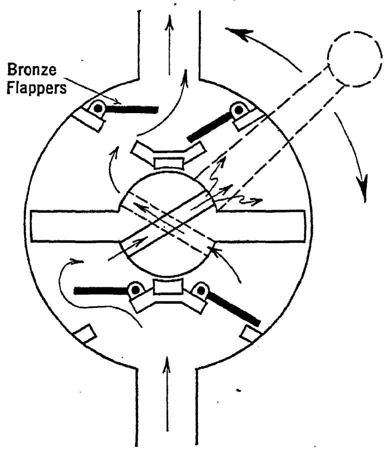


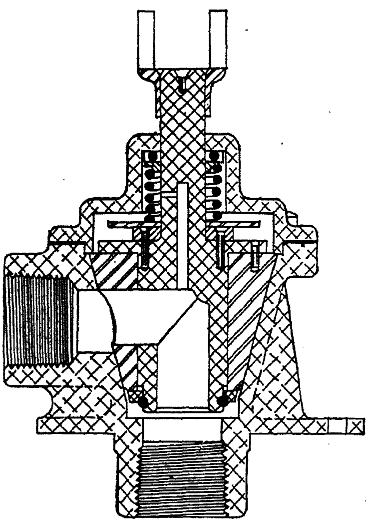
FIG. 77. Hand-operated wobble pump.

Wobble pumps are provided with relief valves to prevent excessive pressures at the carburetor. Both the plain spring and balanced sylphon relief valves are in use. Since there may be considerable pressure loss in the lines between the wobble pump and the carburetor it is necessary to set the wobble pump relief valve static relief pressure higher than the desired pressure at the carburetor. It should be set so that, with the engine running at normal rated power, 120 strokes per minute of the pump will maintain the desired pressure at the carburetor.

In some fuel system installations electrically or hydraulically driven vane-type auxiliary pumps are used. To prevent vapor locks in the fuel supply lines at high altitudes a fuel pump may be installed at the fuel tank outlet. Another method of guarding against vapor locks at high altitudes is to provide a positive air pressure in fuel tanks from some source such as the exhaust side of the engine-driven vacuum pump.

Fuel Valves. Tank selector valves, engine selector valves, cross-feed valves, and other valves are used throughout the fuel system. The cork plug fuel valve illustrated in Fig. 78 is still the most commonly used valve, although it is being replaced by other types which offer fewer maintenance problems. When the cork plug valve stands idle the cork has a tendency to bulge into the valve ports. This bulge makes the valve hard to turn and may result in pieces of the cork being sheared off. Any lubricant placed on the cork plug to make rotation

easier is soon washed away by the fuel. Some operators have provided a means of lifting the plug from the seat to make turning easier. Besides the possibility of shearing cork from the plug a valve which is hard to turn may shear some part of its driving mechanism. When cork plug valves are kept in storage some means should be provided to keep the plug unseated. A piece of wire wrapped tightly around the body of the valve and over the end of the drive stem is satisfactory if the valve is one whose plug tapers toward the driving stem.



Courtesy Aero Supply Mfg. Company

FIG. 78. Cross-sectional view of cork plug fuel valve.

A plug valve which uses a Monel plug and synthetic rubber seats was recently put on the market; it seems to offer good possibilities. Disc-type valves, because of their weight and cost, have not proved very popular. The poppet-type valve is proving popular for use as a tank selector valve.

Fuel valves are often remotely controlled. Linkage between the valve and control may be through rods, tubes, cables, or a combination of these. Linkages should be free from lost motion and should be kept so rigged that the position of the valve agrees with the control indicator. A clicking of the valve will indicate when the port is wide open for a selected position.

Strainers. Strainers are generally located at three positions in the fuel system: at the fuel tank outlet, at the lowest point in the system, and at the carburetor inlet. The tank strainer is of relatively coarse mesh and only prevents sizable particles from entering the fuel lines. The strainer provided at the lowest point in the system has a relatively fine mesh screen. The screen should be removed for cleaning when the engine is checked. A drain in the bottom of the strainer body allows draining of water which may have collected there. The drain should be opened at least daily. The carburetor inlet strainer is of very fine mesh. It should also be removed and cleaned when the engine is checked.

Primers. To provide the necessary amount of fuel required for starting, a priming system is utilized. Priming fuel is usually injected

into the induction system at one of three places: at the carburetor, at the supercharger, or at the inlet port of the cylinders. A priming system which injects the fuel into cylinder inlet ports is illustrated in Fig. 79. Five cylinders of a nine-cylinder engine are usually primed. It is the author's belief that it would be advantageous to omit cylinder No. 2 from the priming system of Fig. 79. In cylinders 1, 8, and 9 any

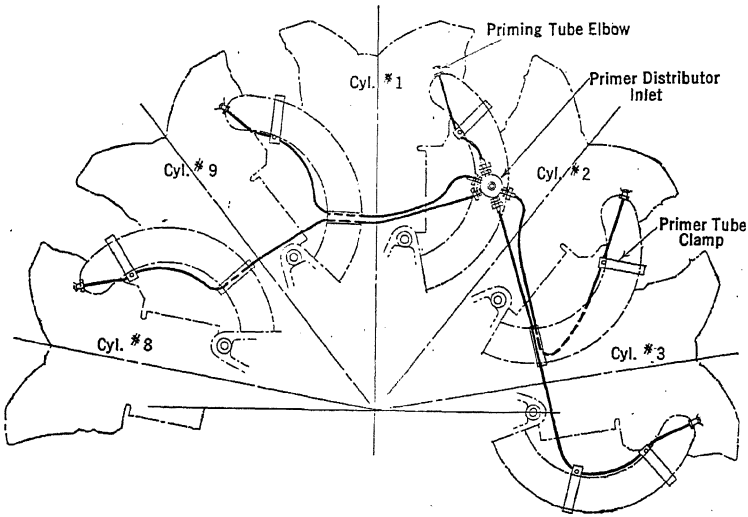


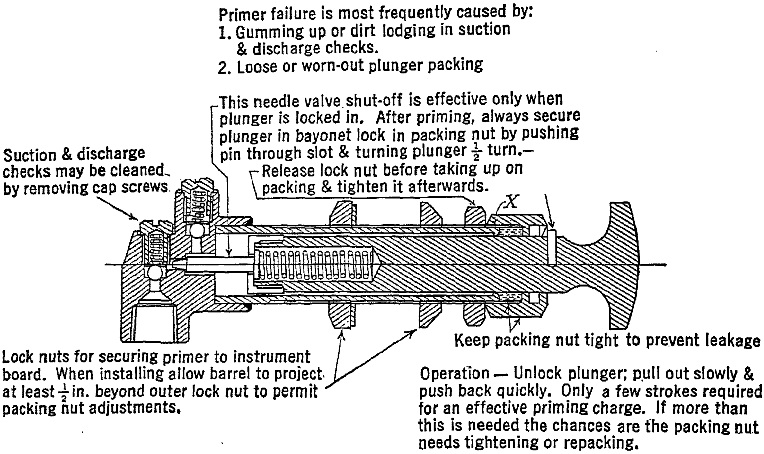
FIG. 79. Individual cylinder priming system.

liquid fuel which enters the combustion chambers has a chance to distribute itself over the piston heads and other parts of the combustion chambers. In cylinder No. 3 the unatomized fuel remains in the inlet port; but, in cylinder No. 2, the liquid fuel is all trapped on the low side of the piston head. The concentration of fuel in one spot will wash the lubricating oil from the cylinder wall and result in chattering of the piston rings, probable piston ring breakage, and scoring of the cylinder wall.

The priming pump is a small piston-type hand pump usually located in the cockpit. On multiengine aircraft one priming pump with a selector valve may be used for all engines. When not in use it is imperative that the pump be shut off. With the pump not off, fuel leakage will occur if the supply line is on the pressure side of the main fuel pump, or air will be sucked into the main fuel lines if the primer supply line is on the suction side of the main fuel pump.

It is undesirable to run long lines from the engine to the cockpit for

priming systems. To avoid this some installations utilize an electrically operated priming valve which merely connects the main fuel system with the priming system. Pressure must, of course, be maintained on the main fuel system to operate the priming system. Some installations utilize the carburetor accelerating pump as a primer pump.



Courtesy The Lunkenheimer Company

FIG. 80. Engine fuel primer pump.

REFUELING

When refueling an aircraft one must make certain of the fuel octane rating requirements. The correct octane rating of the fuel, as well as the capacity of the tank, should be marked on either the tank filler neck cover or a plate immediately adjacent to the filler neck. Some aircraft are equipped to carry different octane fuels in separate tanks. The higher octane fuel is used for take-off and emergency power operation whereas the lower octane fuel is used for cruising. An aircraft should never be refueled with a fuel of octane rating lower than that specified by the engine manufacturer. There is no objection to operating an engine on a fuel of higher octane rating than that for which it is designed, except that increased corrosion difficulties and slightly increased wear will result if the higher octane fuel contains more tetraethyl lead fluid.

On an aircraft with several tanks, when all tanks are not to be filled, the order of filling is specified in the aircraft operation handbook. It is imperative that the tanks be filled in the correct order. If not, take-off may be inadvertently attempted on an empty, or almost empty, tank.

Also, the center of gravity of the aircraft is affected by the order of filling and by the use of fuel from the various tanks.

Water will not mix with gasoline, but it is often found in the bottom of gasoline containers. Its usual source is the condensation of water vapor on the internal surfaces of the container. Water can be eliminated from a container or system by draining at the lowest points of the system. It is good practice to drain all sumps and low points of the fuel system of an aircraft after refueling. Drain cocks are installed in the low points of the system for this purpose. Drainings may be caught in a vessel and observed for water. Waste of gasoline in drainings may be prevented by decanting (pouring the gasoline off the water) and saving the gasoline. If an aircraft sits idle for a period of time the system should be drained for water before the aircraft is used. Water may have condensed in the tanks of the aircraft. This is especially true where there are excessive changes of atmospheric temperature.

Water, as well as dirt and other foreign matter, may be prevented from passing from the storage tank into the aircraft by straining the fuel through a chamois skin. This is a very slow process, though, and is not practical where very large quantities of fuel are handled. When using a chamois, precautions must be taken to prevent its becoming saturated with water. A chamois will prevent the passage of water for a certain length of time only. After the chamois becomes water-saturated, it will discharge the water from one side as fast as it can absorb it on the other side. A more practical method for preventing water from the storage tank from entering the aircraft fuel tank is to make a periodic inspection of the storage tank for water. This can be done by lowering a piece of test paper, erroneously called "litmus paper," into the storage tank. The test paper is changed in color by contact with water. By arranging a strip of test paper on a holder, such as a quantity measuring stick, so that the bottom of the test strip will touch the bottom of the tank and the strip is held in a vertical position, the depth of water in the tank can be determined by the height of color change on the test strip. Some water is almost always present in storage tanks. It must be certain that the inlet of the suction pipe is sufficiently above this water level to prevent the pickup of water as fuel is pumped from the tank.

Dirt and other foreign matter are best prevented from entering fuel tanks by proper storage and handling. Storage tank inlet ports and hand-holes should always be closed except when it is necessary to open them for some purpose. Tank vents should have proper screens to prevent entrance of dirt and foreign matter. A fine mesh screen should

be installed in the outlet line. This is usually provided in the supply hose nozzle.

A very common way for dirt and foreign matter to enter the fuel is through the filler neck of the aircraft fuel tank while refueling is taking place. Every precaution should be taken to prevent this. All small articles should be removed from the shirt or jacket pockets of a refueler before refueling an aircraft. It is very easy, in bending over the filler neck, to have small objects fall from the upper pockets into the fuel tank. These small objects might cause serious trouble by a partial or complete stoppage of fuel flow. In the event that the aircraft is refueled in the rain a proper shield should be provided to prevent water from entering the filler neck.

As an aircraft passes through the air, especially through relatively dry air, it builds up a charge of static electricity. After the aircraft lands it continues to hold this static charge, since it is insulated from the ground by its rubber tires. A ground cable or chain, attached to the aircraft, which will touch the ground is usually provided to discharge this static electricity. This ground cable or chain may not always make good contact with the ground, and therefore it is good practice before refueling to connect a wire, which is known to have a good ground connection, to some metal portion of the aircraft.

With correct proportions of fuel vapor and air, a spark will cause an explosion. It is, hence, imperative that the static electricity be discharged from the aircraft before refueling starts, to prevent static discharge sparks while refueling. If a fuel tender (tank truck) is used for refueling, it, too, should be grounded before and during refueling. While the refueling is taking place the nozzle of the fuel hose should be held in contact with the filler neck of the fuel tank. This will insure the discharge, without spark, of any static charge which might be built up during refueling. A more positive method of preventing an electric potential difference between the filling hose nozzle and the tank is to provide the nozzle with a grounding wire which is grounded to some part of the tank to be filled. Attachment of the grounding wire before the filler cap is removed and detachment after the nozzle is removed will avoid the possibility of a spark occurring as the nozzle contacts or leaves the filler neck. Where a chamois and funnel are used in refueling the funnel as well as the nozzle must be grounded to the fuel tank with a grounding wire. Flexible copper wires with spring-clip connection terminals make very good grounding wires.

In event of refueling at night it should not be necessary to caution not to have open fires in the vicinity of the operation. Flashlights used should be of the explosion-proof type. When a flashlight is turned on

or off a small electric spark is produced. This spark is sufficient to ignite a correct fuel-air mixture. Explosion-proof flashlights are covered to prevent entrance of the fuel vapors to the sparking areas.

Precautions must be taken to prevent the breathing of gasoline fumes while refueling, as it may cause sickness or may even be fatal. Gasoline containing tetraethyl lead is toxic and should not be allowed to get upon the skin. In the event that clothes or skin become wet with gasoline, clothes should be removed at the earliest practicable moment and the skin washed with soap and water. Gasoline burns may be treated the same as fire burns.

CHAPTER V

CARBURETION

The carburetor is not so formidable a mechanism as it first appears to be. Because of the necessity of making it light and compact, the ingenious mechanical features of construction have given it the form of a very intricate and hardly understandable mechanism. Yet, if it could all be laid out in the open and each functioning part of it easily viewed, it would not hold many secrets that could not be readily understood.

The job which the carburetor has to perform is to meter fuel to the incoming air in the correct ratio as required by the engine. To perform this job it must do two things. First, it must measure the amount of air going into the engine. Second, it must meter the fuel to the air in the correct ratio. These are the two functions of any carburetor, be it suction, fuel injection, or other type.

Fuel Requirements of the Engine. Internal combustion engines using gasoline as a fuel will operate on fuel-air mixtures from approximately 0.062 to 0.125 lb of fuel per pound of air. Mixtures beyond these limits will not burn in the cylinder. For all speeds of the engine the best power can be obtained with a fuel-air mixture of about 0.080. However, best fuel economy can be obtained at fuel-air ratios lower than 0.080, as shown on the curve of Fig. 70, page 74. Therefore, since increased power may be obtained by opening the throttle farther, except at and close to full throttle, it is better to operate at the best economy rather than at the best power fuel-air ratio. Still, the best economy mixture is close to the point where irregular operation and backfiring occur and for this reason a slightly richer mixture, known as the best practical mixture, is used.

Because of the air which may leak into the cylinders through the intake valve guides or other parts of the induction system between the carburetor and the cylinders at low manifold pressures, it may be necessary at idling speeds to provide a mixture at the carburetor which is richer than the best practical power ratio in order that a best practical power ratio may be obtained in the cylinders. When approaching full power it is necessary to increase the mixture ratio so as to have best power mixture at full throttle. For the purpose of cooling and for

the prevention of detonation, especially on air-cooled engines, it may be necessary at full power to have a mixture ratio richer than that for best power.

FLOAT-TYPE CARBURETOR

The simplest and still most universally used carburetor is the float type. In this type of carburetor a constant level of fuel is maintained in a float chamber and is sucked into the air stream as the air passes through the carburetor.

The Venturi Tube. As air is sucked into the cylinders it passes through the barrel of the carburetor. The amount of air admitted to the engine is controlled by the throttle butterfly valve. It is necessary that the throttle valve be on the engine side of the carburetor barrel rather than on the intake side of the barrel, or else the metering principle of the suction type carburetor will be voided.

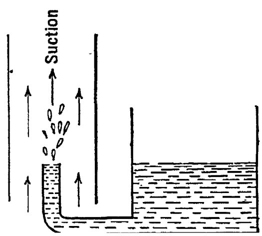


Fig. 81. Air flow through tube and liquid flow from standpipe are both proportional to the amount of suction.

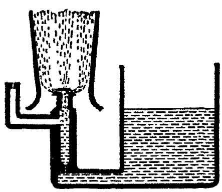
Fortunately, within the range of air velocities used in the carburetor, both the amount of air flow through an opening of fixed size and the amount of fuel flow through an opening of fixed size are substantially proportional to the suction. It may be seen, in Fig. 81, that suction at the top of the barrel is drawing a certain amount of air through the barrel; also, that the suction is drawing a certain amount of fuel from the standpipe in the barrel. The amount of air drawn through the barrel per unit of time is dependent upon the size of the barrel and the amount of suction. The amount of fuel drawn from the standpipe is dependent upon the size of the standpipe opening (or the size of the restriction in the standpipe if one is placed there) and the amount of suction. With the size of both the air and fuel passages remaining constant an increase or decrease in suction will increase or decrease both the air and fuel flow in the same proportion.

For more accurate metering purposes it is desirable to have a higher suction on the fuel jet than that created in the straight barrel of Fig. 81. With more suction on the fuel jet the size of the jet opening may be reduced to give the same fuel flow as a larger opening in a straight barrel. To obtain this greater suction at the fuel discharge nozzle, a venturi tube is utilized.

As a compressible gas passes through a venturi tube the gas is compressed, because of the decreasing diameter of the tube, as it travels

toward the throat of the tube. After the gas passes through the throat it begins to expand, because of the increasing diameter of the tube, and with this expansion it increases in velocity. The expansion and increase in velocity create a suction at the throat of the venturi tube. It is this additional suction at the venturi throat which is utilized to suck fuel from the main fuel discharge nozzle.

The Air Bleed. In order to prevent fuel from continually flowing from the discharge nozzle when the carburetor is not in use, it is necessary to maintain the fuel level a safe distance below the discharge nozzle opening. Hence, before fuel can flow from the nozzle it is first necessary to create enough suction to lift the fuel to the nozzle opening and then an additional suction to cause flow. Also, enough suction must



Courtesy Bendix Products

FIG. 82. A carburetor nozzle employing the "air bleed" principle.

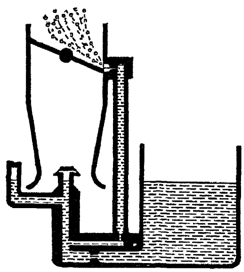


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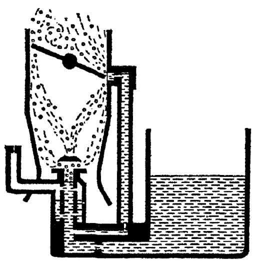
FIG. 83. Carburetor employing idling passage.

be created to break the surface tension of the fuel at the nozzle opening. It is then obvious that the fuel flow from a plain fuel jet is retarded by an almost constant force. This retardation to fuel flow is insignificant at high suctions, but it perceptibly reduces the flow at low suctions. To reduce the amount of suction necessary to lift the fuel to the nozzle opening an air bleed, as illustrated in Fig. 82, is utilized. The amount of suction required to lift the emulsion of air and fuel is considerably less than the suction required to lift a column of fuel only. An air bleed jet gives a substantially uniform mixture throughout its range of operation. The mixture proportion can be modified as desired by the proper selection of the dimensions of the air bleed and emulsion channels.

The Idling System. As shown on the curve of Fig. 70 (page 74), the fuel-air mixture ratio must be greater for low speeds than for speeds in the higher ranges (except full power). At low speeds the main fuel jet may be delivering little or no fuel. Hence, an idling passage, as illustrated in Fig. 83, is provided to carry the fuel up to the throttle valve and intake manifold when the main jet suction is low. The idling system is practically independent of the main jet metering system and

only controls the fuel metering at low engine speeds. As suction increases with the opening of the throttle valve the main jet begins to deliver fuel and the delivery from the idling system decreases.

The Accelerating System. During normal operation the evaporation of the fuel is not necessarily complete in the carburetor or induction system. A part of this unevaporated fuel is in the form of streams of liquid adhering to the manifold walls. The flow of these streams of fuel is slower than the flow of the air and evaporated fuel, but during steady running the streams build up to a sufficient thickness to deliver an average fuel-air ratio at the cylinders equal to that supplied at the carburetor. When the throttle is suddenly opened there is immediately an increase of air and evaporated fuel to the cylinders. However, some time is required for the fuel streams to build up to sufficient thickness to supply the same average fuel-air ratio at the cylinders as is being supplied by the carburetor. Therefore, if the fuel-air ratio supplied by the carburetor remains constant, there will be a temporary condition of " leanness " at the cylinders immediately following a sudden opening of the throttle valve. To offset this condition of temporary leanness the carburetor is provided with an accelerating system which delivers an oversupply of fuel during the acceleration period. The best power mixture should be supplied to the cylinders for quickest acceleration. Hence, a still richer mixture than necessary to prevent temporary leanness is required, if the carburetor has been supplying a best economy mixture.



Courtesy Bendix Products

FIG. 84. Carburetor with accelerating well incorporated in main discharge nozzle.

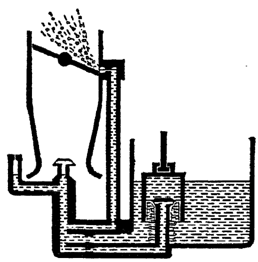


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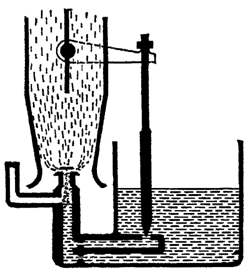
FIG. 85. Carburetor with accelerating pump.

Two types of accelerating systems are illustrated. The accelerating " well," as shown in Fig. 84, is a downward extension or enlargement of the air bleed passage. During steady running this well remains partially filled with fuel. If, now, the throttle is suddenly opened, the fuel

which is in the well, as well as the fuel which is metered through the main metering orifice, is sucked from the main discharge nozzle. Also, if there is any fuel standing in the idling passage, it will supplement the fuel supply to the main discharge nozzle. Thus, the fuel in the well and in the idling system, if any, temporarily supplements the fuel delivered through the metering orifice and gives a rich mixture when the throttle valve is opened quickly.

Engines with long manifold passages, and engines operating under cold conditions where the evaporation of fuel is slow, require greater quantities of fuel during acceleration than the accelerating well around the main discharge nozzle can supply. Carburetors for such engines are equipped with accelerating pumps, as illustrated in Fig. 85. Either the pump cylinder or the pump piston is connected mechanically to the throttle valve lever. As the throttle valve is opened fuel is pumped either to the main discharge nozzle or to a special accelerating nozzle.



Courtesy Bendix Products

FIG. 86. Carburetor with needle valve economizer.

The Economizer System. As will be noted on the curves of Fig. 70 (page 74) the best practical fuel-air ratio must increase to or beyond the best power ratio as the engine approaches full power. To obtain this richer mixture as the throttle approaches full open position, various forms of economizer systems are used. The economizer systems are in reality enriching devices. They derive their name from the fact that it would not be possible to operate the engine at the leaner, better economy mixtures during cruising or lower power speeds if it were not for a device to enrich the mixture at the high power output. Without an economizer system it would be necessary to operate the engine at or above the best power mixture over the complete power range.

The economizer system shown in Fig. 86 merely consists of a needle valve which commences to open when the throttle valve has reached a predetermined position in opening. As the throttle valve continues opening, the needle valve continues opening. The fuel flowing through the needle valve enriches the mixture by supplementing the flow from the main metering orifice to the main discharge nozzle.

The piston-type economizer, as illustrated in Figs. 87 and 88, is also operated by the throttle valve. The lower piston acts as a fuel valve and prevents any fuel from flowing through the economizer system at cruising or lower speeds. The upper piston acts as an air valve and permits air to flow through the separate economizer discharge nozzle at

part throttle. As the throttle is opened the pistons are pushed downward. The lower uncovers the fuel port, allowing fuel to be drawn through the system and out the discharge nozzle. The upper piston cuts off the air bleed to the economizer nozzle, in increments as more holes are closed off, thus increasing the suction on the fuel jet.

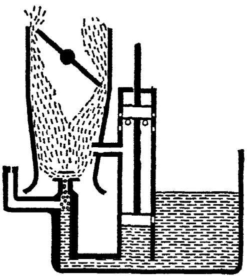


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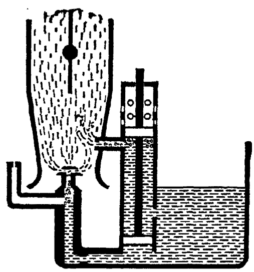
FIG. 87. Carburetor with piston-type economizer (cruise position).



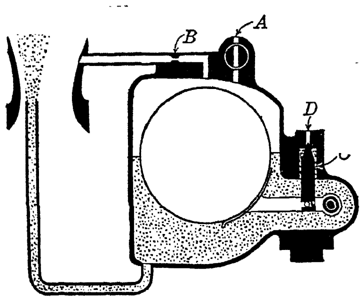
Courtesy Bendix Products

FIG. 88. Carburetor with piston-type economizer (full throttle position).

Some carburetors utilize a pressure-operated economizer system which responds to manifold pressure changes to operate an enrichment valve. The economizer unit consists of an evacuated sealed bellows which responds to the changes in manifold pressure, a calibrated spring to offset the force of the evacuated bellows and to provide the necessary valve travel, and a dash-pot to stabilize the action of the bellows. By having the bellows evacuated it will not respond to changes in temperature, but to changes in pressure only.

Mixture Control. As the airplane gains altitude the atmosphere decreases in pressure, temperature, and density. At a lower density a pound of air will occupy more volume than it would at a greater density. Therefore, for each pound of air taken into the engine a greater volume of air will pass through the carburetor as the airplane ascends. The volume of air passing through the carburetor barrel and the fuel discharged from the nozzle are both proportional to the suction. If, now, the airplane gains altitude, the volume of air passing through the carburetor continues to remain proportional to the suction but the weight of the air passing through the carburetor decreases as the density decreases. With the amount of fuel sucked from the discharge nozzle remaining proportional to the suction, it follows that more pounds of fuel will flow from the discharge nozzle per pound of air passing through the carburetor, as the air becomes less dense. Hence, the fuel-air mixture is enriched as the airplane ascends. The rate of enrichment is inversely proportional to the square root of change in air density.

In order to compensate for this change in mixture either a manually operated or an automatic mixture control is utilized. The mixture supplied by a carburetor may be made leaner by reducing the effective suction on the metering system, by restricting the flow of fuel through the metering system, or by admitting additional air into the induction system through an auxiliary air entrance.



Courtesy Bendix Products

FIG. 89. Carburetor incorporating back suction method of mixture control. Mixture control valve (*A*) located in vent line from float chamber to atmosphere is shown in full rich position (wide open).

Float Chamber Suction Control. Mixture control utilizing the float chamber suction control method is illustrated in Fig. 89. This system is sometimes called the back suction control method. It operates to reduce the fuel flow by placing a certain amount of the air passage suction upon the fuel in the float chamber, so that it opposes the suction existing at the main discharge jet. If the suction above the fuel in the float chamber were equal to the suction at the discharge jet, there would be no flow of fuel from the discharge jet. The suction connection is taken from a location of lower suction than that at the main discharge jet and a small restriction of fixed size is placed in the suction passage. With this arrangement the valve *A*, which is a vent to the atmosphere, may be completely closed without entirely stopping the flow of fuel, since the suction above the float chamber will not equal the suction at the discharge jet.

To obtain a control that is not too sensitive to adjust, the closure of the valve *A* must be rapid at first and then more gradual. This is obtained by the use of a flat disc valve which closes off a good portion of the air vent passage in the first few degrees of rotation; then closes the vent more slowly during the remainder of the rotation.

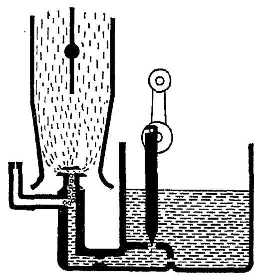


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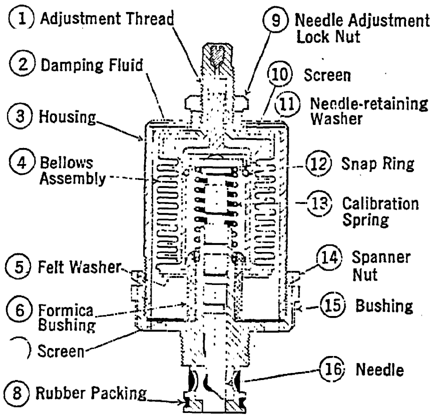
FIG. 90. Carburetor with needle valve mixture control.

Needle Valve Control. The needle valve type of mixture control is used to restrict the fuel passage to the main discharge jet, as shown in Fig. 90. With the mixture control in the full rich position, the needle is in the raised position, and the fuel is accurately metered by the main

restriction in the fuel passage. To lean out the mixture the needle is lowered into the needle valve seat, thus reducing the fuel supply to the main discharge jet. A small by-pass hole, from the float chamber to the fuel passage, permits some fuel to flow, even though the needle valve is completely closed. The size of this opening determines the range of control.

In the back suction method of mixture control, for any given setting of the control the suction in the float chamber increases with suction at the main discharge jet. In the needle type of control the fuel delivery, for any given setting of the control, is proportional to the suction. Hence, it may be seen that in both these types of control any given setting reduces the fuel delivery by the same percentage at all engine speeds while the main jet is in operation.

Automatic Mixture Control. When using the back suction control method of mixture control, an automatic valve in the position of valve *A* (Fig. 89) may be installed. Such a valve is known as an automatic mixture control unit. It consists of a metallic bellows, responsive to variation in both temperature and pressure and operating a contoured valve. It must be remembered that air density varies with temperature as well as pressure. A cross-sectional view of the unit is shown in Fig. 91. The sealed metallic bellows is filled with nitrogen and an inert oil. The nitrogen provides the pressure and temperature response and the oil dampens vibration. As the air density changes, the bellows expands or contracts, moving the tapered needle in the seat; this changes the size of the orifice and regulates the flow of air past the unit. Thus, the suction above the fuel in the float chamber is controlled; this, in turn, controls the fuel flow rate.



Courtesy Bendix Products

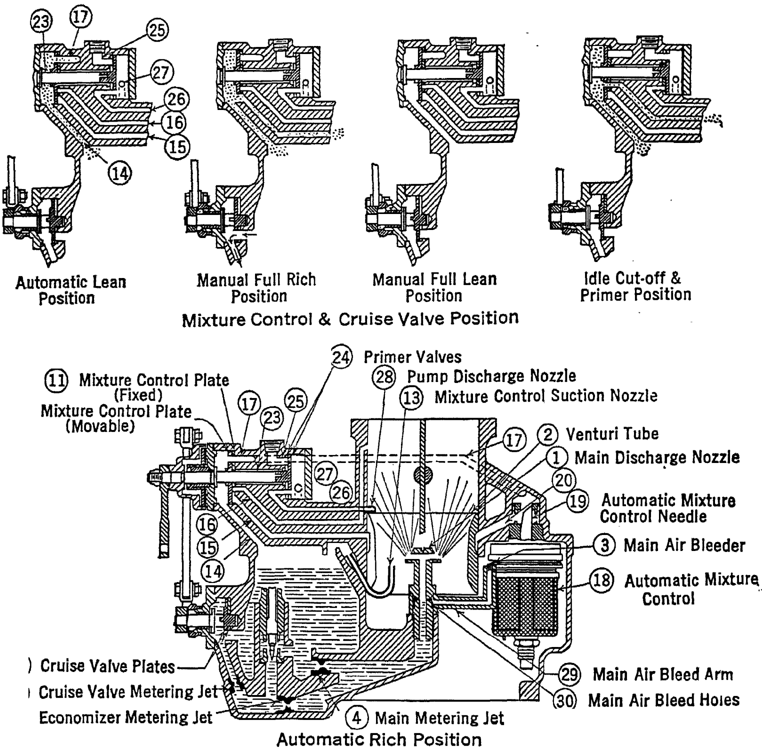
FIG. 91. Automatic mixture control unit.

A carburetor equipped with an automatic mixture control unit is illustrated in Fig. 92. A manually controlled disc valve permits a choice of several mixture conditions.

The atmosphere vent of the float chamber first conducts through passage (14), then through the valve plates (11) and (12) to passage

(17), thence through the automatic mixture control unit valve into passage (20); it finally opens into the space around the outer diameter of the venturi tube.

It will be noted that besides the main metering jet and economizer metering jet there is also a cruise valve metering jet. The fuel supply



Courtesy Bendix Products

92. Carburetor utilizing automatic mixture control unit.

to this jet may be cut off by a valve whose operating arm is mechanically linked with the manually operated mixture control valve.

With the mixture control valve in the automatic rich position, the cruise valve (21) is open and passage (17) is open, allowing the automatic mixture control unit to regulate the suction in the float chamber.

In the automatic lean position the cruise valve (21) is closed, reducing the flow of fuel to the main discharge jet. Passage (17) is still open, though, and allows the automatic mixture control unit to continue regulating the suction in the float chamber.

In the manual full rich position the automatic mixture control unit is cut out of the system by closing of passage (17). The float chamber is vented directly to the atmosphere through passage (15). The cruise valve (21) is open.

In the manual full lean position the cruise valve (21) is closed. All vents to the atmosphere are closed off. Hence, the full suction of the mixture control suction nozzle (13) is acting to restrict the flow of fuel from the float chamber.

Idle Cut-Off. Considerable difficulty may be experienced in trying to stop a high powered engine by cutting off the ignition switch. This is especially true if the airplane has been run or taxied on the ground until the cylinder heads reach a high temperature. After cutting off the ignition switch the cylinder heads may be so hot that autoignition takes place and the engine continues to run. It may kick backwards, which would be very undesirable because of the overstresses that might occur, especially in a geared engine with a heavy propeller.

To overcome this difficulty of stopping and the possibility of kick-back, a method known as the idle cut-off is provided in conjunction with the mixture control disc valve.

When the mixture control valve is placed in the idle cut-off position the float chamber is subjected to the full suction of the barrel through passage (16) (Fig. 92). This passage opens into the barrel above the throttle valve, and when the throttle valve is closed the suction is sufficient to stop all flow of fuel from the float chamber. Without fuel the engine ceases to run.

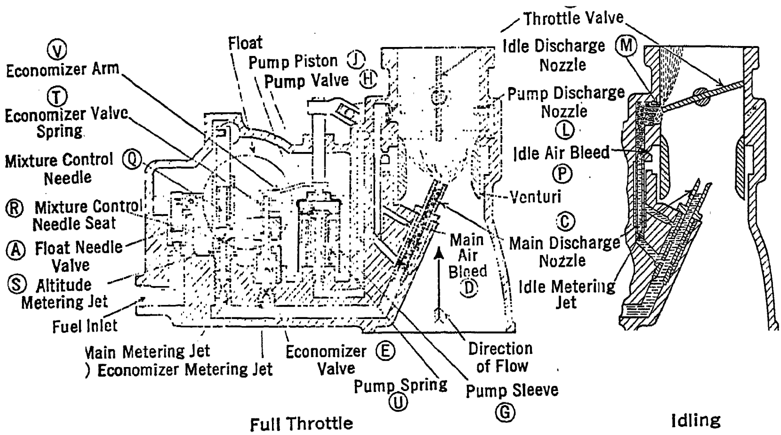
Integral Primers. Some carburetors utilize the accelerating pump for priming the engine. In Fig. 92 it will be seen that in all positions of the mixture control valve, except the idle cut-off position, the accelerating pump passage (27) is connected through passage (26) with the pump discharge nozzle (28). In the idle cut-off and primer position the accelerating pump passage (27) is connected with a threaded outlet from which a tube may lead to the priming system. Opening and closing the throttle will pump fuel into the priming system.

Mixture Control Altitude Range. The range of the mixture control is usually designated in terms of altitude. This means that a carburetor having a correction range of 20,000 ft will give the same mixture ratio at this altitude, with the mixture control set at full lean, as it would give at sea level altitude with the control set full rich. If a metering jet setting is used which gives a mixture richer than necessary on the ground, with the idea of using the mixture control to correct for this condition, the remaining control available for altitude use will

be less than if the sea level altitude jet setting were correct with the control full rich.

The float chamber suction type and needle valve type of mixture controls have a correction range of approximately 25,000 ft altitude. After the limit of mixture control correction has been reached the airplane can ascend 5000 to 6000 ft higher before the mixture will become rich enough to cause the engine to lose power, and several thousand feet more before the engine operation becomes excessively rough.

Location of Atmospheric Vents. The pressure and density of the air entering the carburetor, besides being affected by altitude, are also affected by ram imparted to the carburetor air scoop by the propeller blast. The intensity of ram effect, of course, varies with the slip-stream



Courtesy Bendix Products

FIG. 93. Diagrammatic sketch of Bendix Stromberg NA-R4B carburetor.

velocity. It is very important that any pressure difference caused by the propeller blast act equally on both sides of the fuel-metering jet, so that the fuel flow will be responsive only to the difference in pressure resulting from the flow of air through the carburetor. To insure this condition, the float vents, or mixture control openings, are brought to the air entrance of the carburetor. Any pressure difference resulting from the propeller blast or forward motion of the airplane is thereby balanced equally on the float chamber and on the fuel jet.

The air intake attached to the carburetor may cause turbulent or irregular flow of air into the carburetor so that different pressures will exist at various locations in the carburetor entrance. In order to obtain an average of these pressures in the float chamber, or mixture control

openings, the vent passage, on some carburetors, opens into an annular space between the venturi tube and barrel formed by a groove in the outside diameter of the venturi tube. This annular groove is connected to the air intake by four slots milled in the outside diameter of the venturi tube. This arrangement permits the use of carburetor air scoop intakes of various designs without affecting the metering characteristics of the carburetor.

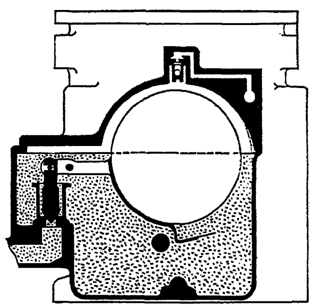


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FIG. 94. Level flight; normal feed to jet; normal float action.

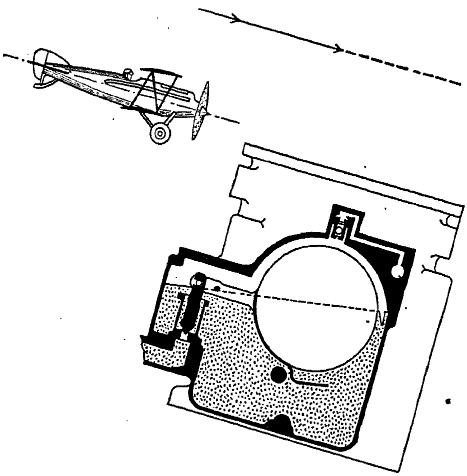

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FIG. 95. Dive; normal feed to jet.

Float Mechanism. The fuel flow from the carburetor should be subject to no other force than the suction resulting from the air flow through the carburetor. It is, therefore, necessary to provide a separate constant level reservoir or float chamber between the main gasoline tank and the metering system of the carburetor. Within the float chamber there is a float which rises and falls with the fuel level. The hinged arm, to which the float is attached, operates a needle valve that controls the flow of fuel into the fuel chamber from the main fuel supply. With no fuel in the carburetor the float is at its lowest position and the needle valve is open. As fuel is admitted from the supply line, the float rises and closes the valve as the fuel reaches the proper level. When the engine is running and fuel is being drawn out of the float chamber to the jets, the valve does not alternately open and close, but takes an intermediate position such that the valve opening is just sufficient to supply the required amount of fuel and keep the level constant. The

running level is approximately ⅛ in. below the standing level, and the vibration keeps the fuel splashing considerably above this level.

Fuel Pressure. The float mechanisms in carburetors for use with fuel systems incorporating a fuel pump are designed to operate at 2 to 4 lb per sq in. fuel pressure, and 3 lb pressure is recommended for service use. Special float needle valves and seats may be installed for use with gravity feed fuel systems having 2 lb per sq in. pressure or less.

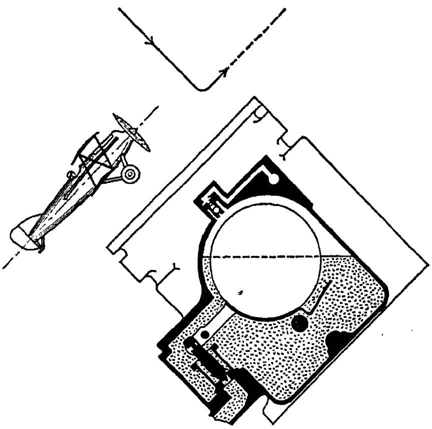

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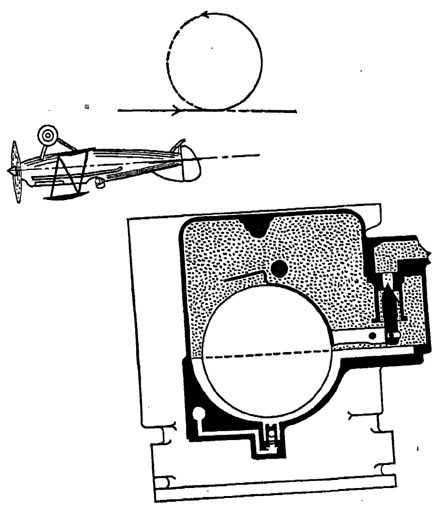
FIG. 96. Zoom following dive or continuous steep climb; normal feed to jet.

Float Action During Maneuvers. The operation of the float mechanism and the position of the fuel during different maneuvers of the airplane depend not only upon gravity, but also upon the effects of inertia and centrifugal force. It is necessary that the float mechanism operate positively at all angles and positions where power is demanded from the engine, and it should not permit leakage of gasoline at any of these positions.

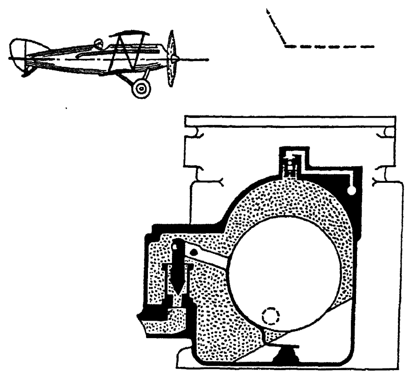
Figs. 94 to 99 show the approximate position of the fuel in the float chamber during normal level flight and during some of the commonly executed maneuvers. It will be noted from these illustrations that the passage leading to the metering system is always covered with fuel so the fuel feed to the engine is not interrupted.



Courtesy Bendix Products

FIG. 97. Loop without stall; normal feed to jet.

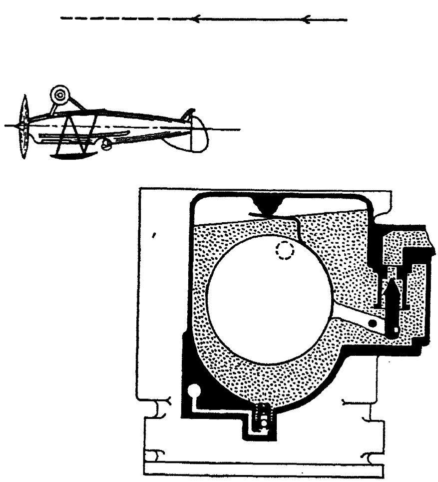
If the engine is equipped with a fuel pump and a fuel system which will supply fuel while the airplane is in an inverted position, the fuel pump line pressure is exerted on the metering system and an excess amount of fuel may be supplied to the engine. Carburetors designed for inverted flying are equipped with a check valve in the inlet passage which operates in the inverted position to allow only sufficient fuel flow for full throttle operation.



Courtesy Bendix Products

FIG. 98. " Air pocket " or start of dive; float action reversed; normal feed to jet if gravity fuel system or if check valve is installed in fuel supply inlet of pressure system.

Older types of aircraft carburetors were designed with the float chambers either ahead of or behind the carburetor barrel and fuel discharge nozzle. With such a design the main jet was considerably above or below the fuel level when the airplane was standing with tail down or when diving or climbing at steep angles. When the main jet was above the fuel level there was a tendency toward a lean mixture; when below, there was a tendency for fuel to leak out. In later types of carburetors the fuel discharge nozzles are located in line laterally with the center of the float, with the result that the fuel flow is not disturbed in any normal flying position.



Courtesy Bendix Products

FIG. 99. Upside down flight; flat action reversed; continuous feed to jet if fuel pump is used.

Fuel Strainers. In most carburetors, the fuel supply first enters a strainer chamber where it must pass through the strainer screen, which intercepts any dirt

particles which might clog the needle valve opening or, later, the jets. Strainers are generally retained by a strainer plug and compression spring, and can be readily removed when the strainer plug is taken out. By removing the strainer the strainer chamber can be thoroughly drained and flushed out.

Carburetor Construction. The air capacity of the carburetor is limited by the size of the venturi tube. Venturi tubes are made in different sizes from which selections may be made according to the requirements of the engine to which the carburetor is fitted. A size is usually selected to provide, at normal full speed and load, an average air velocity of 300 ft per sec through the throat of the venturi tube.

For additional air capacity more barrels are added to the carburetor. Carburetors with two and three barrels are usually arranged so that all throttle butterfly valves are on the same shaft. Four-barrel carburetors usually have two throttle shafts synchronized by gear segments with two butterfly valves on each shaft. The throttle valves must always be located on the engine side of the venturi tube and discharge jet.

Metering jets are most generally of the fixed-orifice type. The size of the orifice is expressed in the equivalent twist-drill size. The sizes of the orifices used are determined at the factory by actual test of the carburetor on the type of engine on which it is to be used. These orifices should not be changed in size without recommendations from the manufacturer. Wires or metal tools of any kind should never be used to assist in removal of metering jets as they will damage the metering orifice. If the jet is located in a long horizontal passage, a stick of wood cut to fit tightly in the approach may be used to withdraw the jet from the passage.

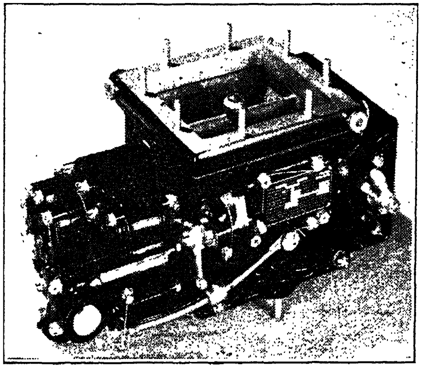
Carburetors are designed to be mounted on the engine so that the air either passes up or passes down through them. Those in which the air passes downward are known as downdraft and those in which the air passes upward as updraft carburetors.

Not all carburetors necessarily incorporate all the features previously described. Some of the smaller carburetors for the low powered engines do not incorporate the economizer or mixture control. The automatic mixture control will only be found on carburetors of larger capacity and later design.

DIAPHRAGM CARBURETOR

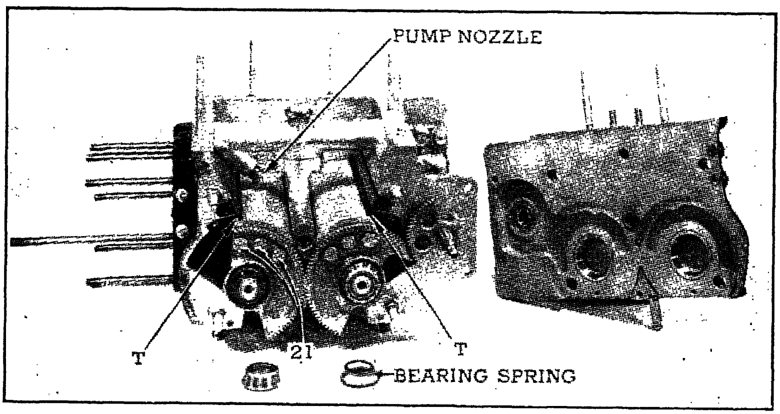
Two types of ice formation are encountered in the engine induction system. Atmospheric ice, not affected by the carburetor design, may form in the induction system, especially in the carburetor intake scoop:

Another type of ice formation resulting from the vaporization of the fuel may form in the carburetor. This type of formation may be eliminated or its effects reduced by carburetor design. As soon as the fuel leaves the discharge nozzle it begins to vaporize. A certain amount of heat, known as the heat of vaporization, is required to vaporize the fuel. This heat must be furnished by the air with the result that the temperature of the air drops 30 to 40 Fahrenheit degrees. The cold air cools off the surrounding carburetor parts. If the humidity of the intake air is high enough, some of the water vapor of the air will be condensed as the air drops in temperature. A portion of this moisture, which impinges on parts such as the venturi tube and throttle valve, will form ice if chilled below 32°F.



Courtesy Holley Carburetor Company

FIG. 100. The Holley diaphragm-type carburetor.



Courtesy Holley Carburetor Company

FIG. 101. Main body of the Holley carburetor, showing the venturi throttle valves.

Except at full throttle, a further cooling of the mixture takes place as it passes the throttle valve, because of the drop in pressure.

By designing the carburetor so that fuel is discharged beyond the

throttle and so that the fuel-air mixture does not flow over any abrupt corners or shapes during its passage, the chances of ice formation due to the vaporization of the fuel are small. Owing to the principle of operation, this is difficult to accomplish in a float-type carburetor. For this reason the float-type carburetors are being superseded by the diaphragm and pressure injection carburetors on the higher powered engines. Another advantage of these kinds of carburetors is that they are not affected like the float-type carburetor by rapid maneuvers and rough air, because they maintain a full fuel chamber.

The Holley Carburetor, Model F. The Holley carburetor has a single air passage into which fuel is supplied from a single fuel supply chamber. The fuel is sucked into the air passage by the same suction which draws the air through the carburetor. In this respect the principle is the same as in the float-type carburetor. However, this type of carburetor is unlike those of other designs in that the supply chamber float mechanism is replaced by a diaphragm mechanism; also, in that the control of the air passage is accomplished by means of a variable venturi rather than by the conventional butterfly valve and fixed venturi.

The fuel discharge nozzle and venturi throttles are arranged in such a way that the carburetor is inherently free of ordinary icing troubles. Also, the type of fuel-metering system and throttle used in this carburetor provides compensation for changes in altitude. However, in order to obtain more exact altitude adjustment and increased economy under favorable operating conditions, a manual control is provided for leaning out the fuel-air ratio.

Main Body. The main body of the carburetor consists of two end blocks bolted between two side plates. The two throttles, the metering channel, the discharge nozzle, and the throttle shaft are assembled with the main body. The throttles are made in the form of modified cylindrical sectors having the discharge nozzle located between them and forming a streamlined venturi-shaped passage for all degrees of opening. The throttles fit in the main body with a small end clearance and are sealed against leakage by means of a leather brush which bears lightly on the top of the cylindrical surface. A gear on each throttle and one on the throttle lever shaft serve to drive them in synchronism. The throttles are mounted on roller bearings and the throttle shaft on ball bearings. In the earlier types of these carburetors the throttles functioned in oilless bushings.

The main diaphragm mechanism is fastened to the left side of the carburetor as a unit by means of nine studs and can be removed and replaced without disturbing other parts of the carburetor. The mix-

ture control valve is self-contained in a small casting fastened to the rear face of the carburetor and may also be removed intact.

The carburetor is vented through a hollow rectangular casting which matches the air entrance and is provided with a number of small holes around the inside surface. This helps to obtain an average of the pressure existing at the entrance to the carburetor. Drilled passages lead from this vent ring to the space outside the two main fuel diaphragms.

Fuel Chamber. The diaphragm mechanism, which is located on the left side of the carburetor, consists of two similar diaphragms placed side by side and forming a fuel chamber between them. Each diaphragm is flexibly connected at its center to a lever, the other end of which bears on the end of a fuel valve. This valve is a ball-ended plunger sliding in a guide which also forms the seat. Fuel under pressure from the fuel pump enters through this valve and fills the chamber between the diaphragms. The weight of this fuel causes the diaphragms to bulge outward, thereby forcing the valves against their seats by means of the levers. When the fuel reaches a certain height in the chamber between the diaphragms its weight exerts enough force on the diaphragms to close the fuel valves against the fuel pressure.

The outlet of the fuel chamber is at the top. Suction from the fuel discharge nozzle is carried back to this point and tends to draw the diaphragms together, thereby allowing the fuel valves to open and admit more fuel. Thus, at all times when the engine is running, the diaphragm chamber is entirely filled with fuel; this eliminates trouble arising from splashing — and the resulting interruption of fuel flow — during violent maneuvers. By virtue of the symmetrical arrangement of the diaphragm section the carburetor will function in inverted flight as well as right side up.

Main Fuel-Metering System. The main discharge nozzle is connected with the fuel chamber by the main metering passage. Located in the main metering passage is a restriction and a tapered metering needle. This needle is actuated, through a cam lever, by a cam attached to the shaft which is geared to the throttles. Thus, as the throttles are opened to increase the air passage, the fuel passage opening is correspondingly increased to provide the proper fuel flow. It is here that the metering characteristics of this carburetor differ from the float type of carburetor. In the float-type carburetor the size of the main metering orifice remained constant and the fuel flow increased with air flow because both were dependent upon the increase in suction. However, in the Holley carburetor, the air flow is not increased by an increase

of suction through the venturi, but by making the venturi opening, which is in itself the throttle, wider. Hence, if the suction on the main discharge nozzle does not increase with increased air flow, it is necessary to open the metering restriction wider to provide an increase in fuel flow and maintain the same fuel-air ratio. The cam which actuates the metering needle is designed to provide an approximately constant mixture ratio for all throttle openings above the idling range. An air bleed is provided just above the vertical passage to the main discharge nozzle. This bleed helps emulsify and stabilize the flow of fuel. It also prevents syphoning of fuel from the main fuel chamber when the throttle opening is reduced.

Idling System. When in the idling position the rotating venturi throttle valves are practically closed, having about 0.005 in. clearance between them and the nozzle bar to permit sufficient air to pass for idling purposes. This clearance is governed by a throttle adjustment screw. The main metering needle is opened sufficiently to provide an excessively rich mixture. The amount of fuel drawn past the metering needle is regulated by the amount of air passing through the idling mixture adjustment valve. This valve is operative only when the throttles are nearly closed (engine idling) since it bleeds air through a passage in the center of the metering needle shank which shuts off as soon as the needle is moved out of the seat about $\frac{1}{16}$ in. Thus, the idle adjustment is not effective for engine speeds above approximately 1000 rpm.

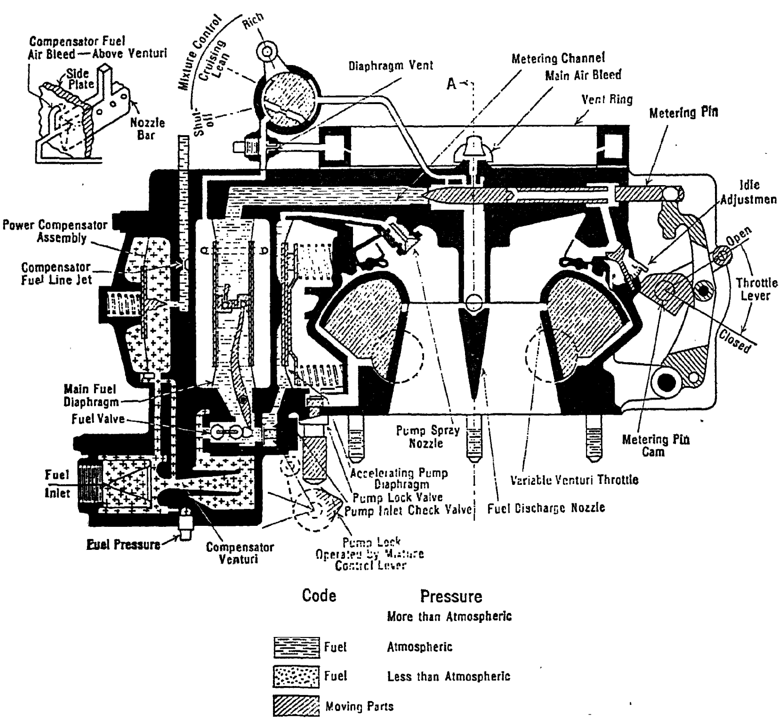
Power Compensator. The power compensator on the Holley carburetor serves the same purpose as the economizer on the float-type carburetor. It is an enriching device which goes into operation as the engine approaches full power.

A venturi is provided in the fuel inlet. When there is a flow of fuel through this venturi, the pressure at the throat is less than the pressure at the entrance. The greater the fuel flow through the venturi, the greater the difference in pressure between the entrance of the venturi and the throat. This difference in pressure is used to operate a spring-loaded needle valve. When the fuel flow is increased to the point where the venturi differential pressure equals the initial tension on the spring, the needle valve starts to open. Further increase in the flow through the venturi increases the needle lift. This valve supplies an additional quantity of fuel directly from the fuel entrance to the compensator discharge nozzle through the external tube located on the rear side of the carburetor.

Thus, while the diaphragm mechanism and main metering system supply the engine with a mixture of approximately constant "basic" or normal cruising strength, the compensator supplies automatically

the additional fuel required to give the richer mixture desired at higher power outputs. There is no mechanical connection between the power compensator and the throttle mechanism.

The details of the power compensator may be noted in Figs. 102 to 104. The tapered needle is attached to a flexible diaphragm, and is held against its seat by a spring. The chamber in which the needle and seat are located is connected to the fuel supply ahead of the venturi



Courtesy Holley Carburetor Company

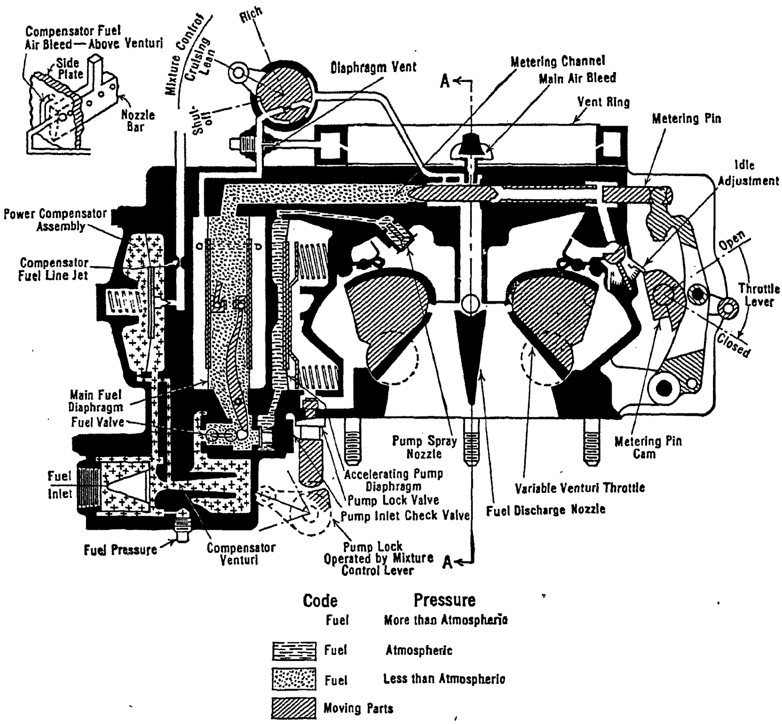
FIG. 102. Diagram of Holley Model F aircraft carburetor — controls in take-off position.

entrance. The other side of the diaphragm is connected to the throat of the compensator venturi. The spring is adjusted so that the compensator starts to operate at the specified fuel flow, and the greater the fuel flow beyond this point of opening, the greater will be the opening of the needle.

The power compensator is calibrated to provide the proper amount of fuel with 6 to 7 lb pressure at the carburetor. This pressure must therefore be maintained, especially at high power output when the

compensator is operating. A change in pressure of 1 lb will produce about 2 per cent change in mixture when the compensator is operating. At low outputs when the compensator is not operating the mixture is not affected by changes in fuel pressure.

Accelerating Pump. To insure rapid and positive acceleration of the engine it is necessary to provide an additional quantity of fuel

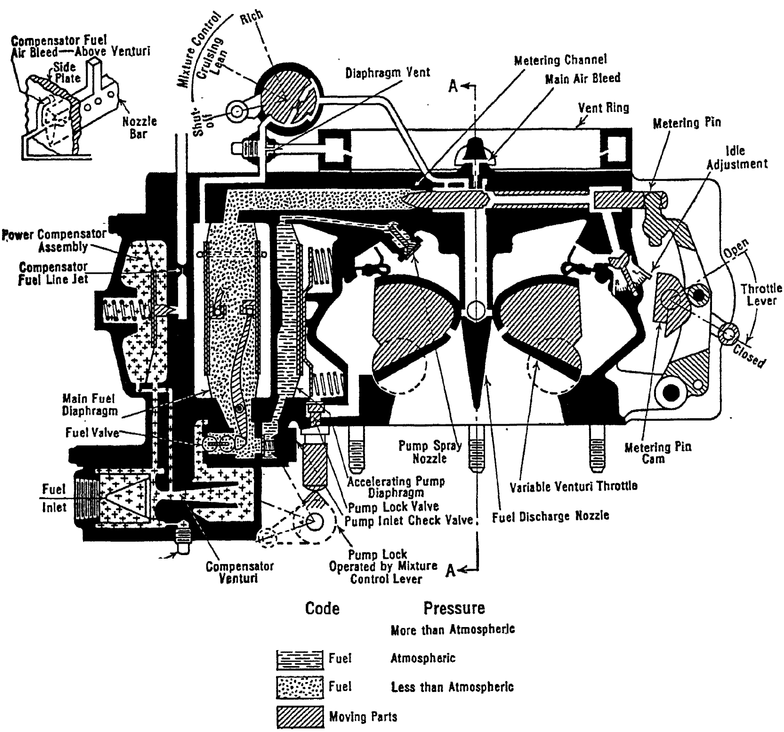


Courtesy Holley Carburetor Company

FIG. 103. Diagram of Holley Model F aircraft carburetor — controls in cruising lean position.

when the throttles are quickly opened. For this purpose a vacuum-operated diaphragm type of accelerating pump is provided. This is located between the main diaphragm mechanism and the body of the carburetor. The complete pump mechanism consists of an inlet check valve, an outlet spray nozzle, a diaphragm, three springs for moving it, and the pump lock valve. One side of the diaphragm is open to the vacuum that exists below the carburetor when the throttles are closed and the engine running, and the other side forms a gasoline

chamber with the inner wall of the main diaphragm mechanism. The springs are on the vacuum side of the diaphragm and tend to apply pressure on the fuel on the other side of the diaphragm. The inlet check valve is located in the bottom of the main diaphragm fuel chamber and the outlet spray nozzle is located under the metering channel and directs the accelerating charge down into the air passage of the



Courtesy Holley Carburetor Company

FIG. 104. Diagram of Holley Model F aircraft carburetor — controls in idle shut-off position.

carburetor. The accelerating pump lock valve is in the passage leading to the vacuum side of the diaphragm and is closed when the mixture control lever is moved to the idle cut-off position. This valve prevents the pump from operating when the engine is being stopped.

When the engine is idling the high vacuum below the throttles pulls the pump diaphragm against the springs and draws a charge of fuel into the pump chamber through the inlet check valve. When the throttles are opened this vacuum is broken and the springs compress

the fuel in the pump chamber and discharge it through the spray nozzle. The action of the pump is automatic, there being no mechanical linkage between the pump and the throttles. This type of carburetor, therefore, cannot be used to prime or flood the engine by opening and closing the throttles with the engine not running.

Mixture Control. It is characteristic of the design of the carburetor, with its particular combination of diaphragm mechanism, metering system, and venturi throttle mechanism, to compensate partially for altitude without the use of any auxiliary mixture control device.

A manual mixture control, however, is provided to permit leaning out to obtain more exact altitude adjustment and improved economy when cruising.

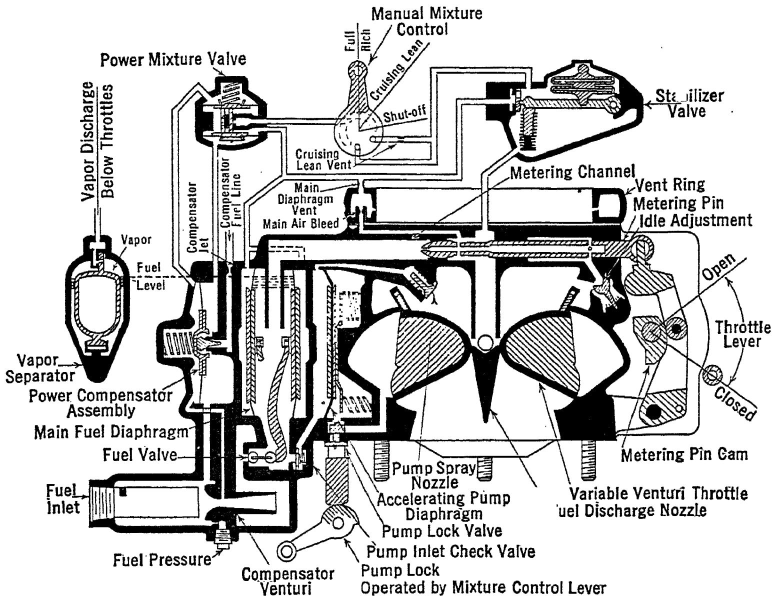
The actual effect of the mixture control valve is to apply to the air space outside the main diaphragms a percentage of the same suction that exists at the metering needle. This reduces the suction available for drawing fuel out of the diaphragm chamber and results in a decreased pressure drop across the fuel-metering restriction which gives a decreased fuel flow and a resulting leaner mixture.

The amount of suction is regulated by varying the area of the mixture control valve passage which admits the suction to the air space outside the diaphragms. In the "full rich" position this passage is completely closed; as the control is moved toward the cruising lean position a small slot on the mixture control disc is gradually opened. The amount of suction is further controlled by a restriction in the passage connecting the space outside the diaphragms to the vent ring. This restriction bleeds off a portion of the suction and its size is selected so that with the mixture control in "cruising lean" position, the mixture strength throughout the cruising range will not be less than the allowable minimum. Movement of the mixture control lever leans out the mixture over the entire range of operation from idle to full throttle.

Idle Cut-Off. A further function of the mixture control is to shut off the flow of fuel, preventing the engine from after-firing when it is stopped. This is accomplished by moving the mixture control to its full travel beyond the "cruising lean" stop. This exposes the outside of the diaphragms to practically the same suction as exists at the fuel-metering restriction and at the same time locks the accelerating pump. With the suction thus balanced the diaphragms act to close the fuel inlet valves and hence all fuel supply is cut off.

The Holley Carburetor, Model H. The Model H Holley carburetor is of the same basic design as the Model F. It incorporates several automatic features and a number of mechanical improvements not present in the Model F. The major changes are the addition of a

stabilizer valve (automatic mixture control unit) to provide automatic altitude, temperature, and engine load compensation; a built-in vapor separator which removes any air or vapor from the gasoline before it reaches the metering orifice; a power mixture valve which makes it impossible for the pilot to use cruising lean mixtures at high power output, which might cause serious damage to the engine, and the addition of a revised idle system which provides appreciably greater range of adjustment of the idling mixture.



Courtesy Holley Carburetor Company

FIG. 105. Diagram of Holley Model H aircraft carburetor - - controls in idling position.

Stabilizer Valve. Referring to the diagrammatic sketch, Fig. 105, it will be noted that the stabilizer consists of a slide valve operated through a lever by the movement of sealed capsules which are filled with air at substantially atmospheric pressure and temperature. These capsules expand and contract for variations in pressure and temperature and thereby cause movement of the slide valve which acts to regulate the mixture ratio. The slide valve is connected in parallel with the manual mixture control valve and functions in the same manner; that is, by controlling the pressure behind the main fuel diaphragms. The stabilizer, therefore, functions in effect as a self-operating mixture

control valve which responds to variations in altitude, temperature, and engine load.

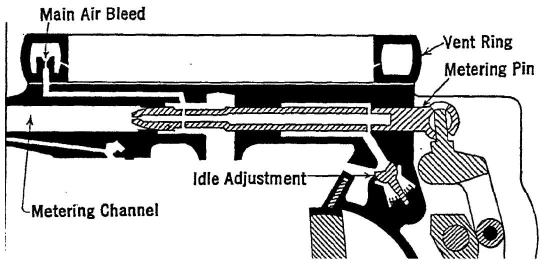
The stabilizer is in operation at all times, both in full rich (or automatic rich) and cruising lean (or automatic lean) positions of the manual mixture control. The stabilizer chamber is connected to the discharge nozzle and, therefore, responds to any conditions which affect the nozzle suction and hence the flow of fuel.

Vapor Separator. Aircraft gasolines tend to release vapor and entrained air in normal flight operation because of several conditions, among which are the reduction in atmospheric pressure which occurs at altitude, the agitation and turbulence caused by the fuel pump, fuel pump relief valve, and elbows in the fuel line; and vaporization caused by any temperature rise which may take place in the fuel system. Along with this, the agitation of the gasoline flowing through the fuel inlet valves of the carburetor itself causes an additional liberation of vapor. This vapor is objectionable in that it affects the metering characteristics of the carburetor if allowed to pass through the metering orifice. It is therefore important that this vapor be removed before the gasoline is metered in the carburetor. In the Model H carburetor, this is accomplished by the addition of a float-operated valve placed within the diaphragm chamber of the carburetor. The diaphragm chamber has been modified to move the fuel inlet valves to the top so that any vapor which is liberated at this point will have easy access to the vapor separator. The fuel is withdrawn from the diaphragm chamber at a point close to the center of the diaphragms; this assures that only the vapor-free gasoline will go to the metering orifice. Any accumulation of vapor in the upper part of the diaphragm chamber causes the vapor float to descend and open the vapor separator valve, thereby connecting the diaphragm chamber to the region below the throttles, which is always at a higher suction than the diaphragm chamber. The vapor is therefore withdrawn and the level in the diaphragm chamber will then rise and cause the vapor separator float to rise with it and shut off the vapor separator valve. The action of the vapor separator float does not interfere with the normal action of the main fuel diaphragms. The main fuel diaphragms respond to the head or pressure of fuel against them, whereas the vapor separator float responds only to the level of gasoline within the diaphragm chamber as determined by the relative volume of vapor and gasoline present.

Power Mixture Valve. This valve overrides the action of the manual mixture control valve and automatically restores the full rich mixture whenever the engine reaches a predetermined percentage of rated power, as indicated by the rate of fuel flow through the compensator venturi.

The power mixture valve is in series with the manual mixture control valve; it functions by closing the manual mixture control valve passage. This occurs when the rate of fuel flow through the compensator venturi for which the valve was adjusted is exceeded; this would happen when a certain power output was being exceeded.

The timing and operation of the power mixture valve are controlled in identically the same manner as the compensator valve described above. As long as the mixture control is left in the full rich position, the power mixture valve has no effect. If the manual mixture control is in the cruising lean position and the pilot should attempt to use take-off power, the power mixture valve will override the action of the manual mixture control and will provide normal full rich mixtures for take-off power. If, after this, the power is reduced to below the maximum permitted for cruising lean operation, the power mixture valve will return to its original position and restore the cruising lean mixtures existing before the excessive power was applied.



Courtesy Holley Carburetor Company

FIG. 106. Diagram of the Holley Model H idling system.

Idling System. It will be seen in Fig. 106 that the metering needle used in the Model H carburetor has a small hole in the point which supplies the fuel for idling. Hence, the needle does not have to remain partially open for idling. The fuel enters the hollow portion of the metering needle under a pressure differential determined by the position of the idle adjustment valve, which is an air valve similar in construction to that used in the Model F carburetors. The suction within the hollow portion of the metering needle is increased as the idle mixture adjustment lever is moved to the rich (down) position, thereby shutting off the idle air bleed. This causes a greater flow of fuel through the small idle orifice in the metering needle and, therefore, provides for a richer idle mixture. When the idle mixture adjustment is moved to the " up " position, in which the air bleed valve is open, the mixture

becomes leaner. This construction provides for approximately twice the range adjustment which is obtainable with the Model F type of idle mixture adjustment system.

INJECTION CARBURETOR

The injection carburetor, like all carburetors, measures the flow of air into the engine and meters fuel to provide the correct fuel-air mixture ratio. Unlike other carburetors, though, the fuel is metered through orifices under a pressure higher than atmospheric. The fuel is atomized under positive pump pressure by the main discharge nozzle which is located on the engine side of the throttle valve. Some of the advantages claimed by this construction are as follows:

1. No ice formation from vaporization of fuel.
2. Complete maneuverability. Gravity and inertia effects are negligible
3. Accurate metering at all engine speeds and loads, independent of changes in altitude, propeller pitch, or throttle position.
4. Pressure atomization of the fuel resulting in increased economy, flexibility, and smoothness.
5. Simplicity and uniformity of settings.
6. Protection against fuel boiling and vapor lock.

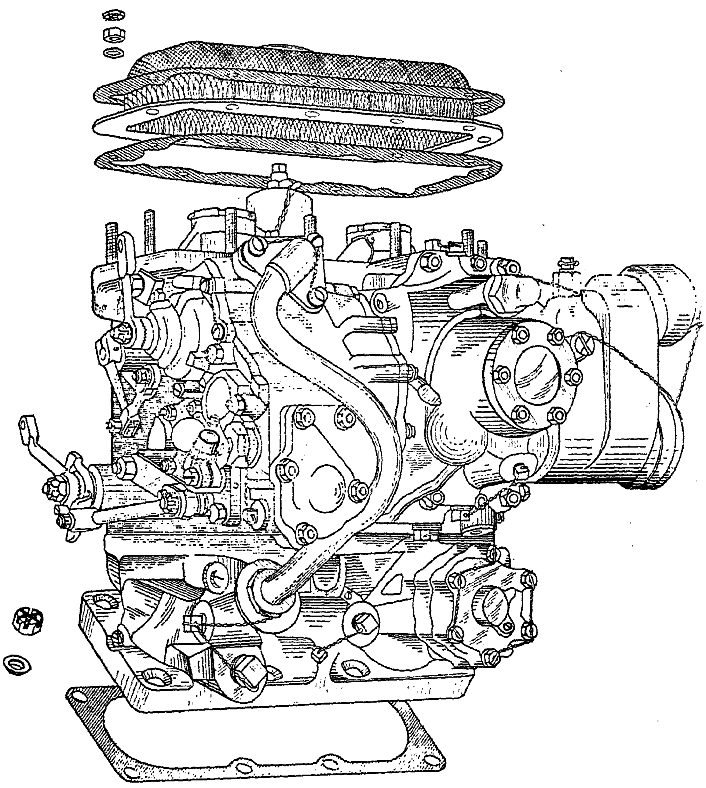
Units of the Bendix Stromberg Injection Carburetor. The *throttle unit* of the injection carburetor is similar to that used with conventional float-type carburetors. It has a butterfly type of throttle valve, a large and a small venturi, provision for mounting an automatic mixture control unit, and a flange for mounting the regulator unit. A manually operated valve to by-pass the automatic mixture control and make it inoperative also is included in the throttle body design.

The suction at the throat of the small venturi is a measure of the amount of air entering the engine. This suction, when corrected by the automatic mixture control for changes in air density, becomes a measure of mass air flow and is applied to the air diaphragm of the regulator unit to regulate the fuel-metering pressure (or head) across the fixed jets in the fuel control unit.

The *automatic mixture control unit* consists of a sealed metallic bellows operating a contoured valve. The bellows is filled with a measured amount of an inert gas to make it sensitive to temperature as well as pressure changes. The valve, therefore, has a predetermined position for each air density encountered in flight.

The *regulator unit* automatically adjusts the fuel pressure across the metering jets and, therefore, the fuel flow in proportion to the mass

air flow through the throttle body. The unit is made up of an air diaphragm, a fuel diaphragm, and a balanced fuel valve, all mounted on one stem supported on suitable guides. Fuel enters through a strainer, passes through the balanced valve to one side of the fuel



Courtesy Bendix Products

FIG. 107. Bendix Stromberg injection carburetor complete with mounting gaskets and air screen.

diaphragm chamber and then to the jets in the fuel control unit. A vapor separator is provided in the strainer chamber to prevent vapor from entering the regulator.

The *fuel control unit,* attached directly to the regulator, contains the metering jets, an economizer valve, an idle needle, and a manually operated mixture control and mixture selection valve. The economizer valve is operated by an air diaphragm and provides enrichment in proportion to mass air flow through the carburetor. The idle needle

is mechanically connected to the throttle and controls the mixture throughout the idle range of speeds. The manual mixture control provides full rich, automatic rich, automatic lean, and idle cut-off positions.

The *fuel discharge nozzle* is supplied with fuel from the fuel control unit. It is spring-loaded and does not open until a predetermined pressure is reached. The nozzle may be installed on the engine induction system itself if a suitable fitting is provided; it may be installed on the adapter which adapts the carburetor to the engine, or, in some carburetors, it may be incorporated in the body of the carburetor.

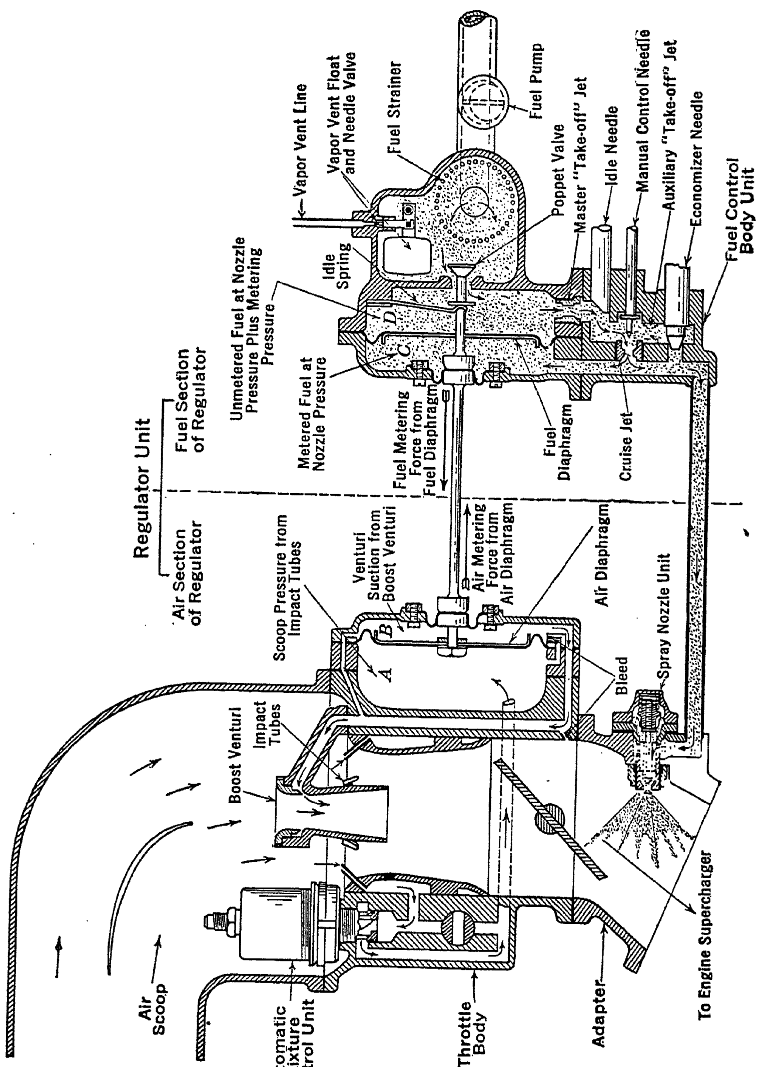
Throttle Unit. The throttle unit follows conventional carburetor lines in that it comprises a throttle, a venturi tube system for developing suction, and a group of impact tubes for collecting the average entrance pressure. A venturi tube loses greatly in efficiency when a fuel spray is delivered within it. In this system, in which such disturbance is absent, it has been possible to obtain more than twice the metering suction per unit resistance obtainable in previous carburetors, with a very marked increase in metering range and also in accuracy of mixture regulation.

Regulator Unit. The regulator unit may be considered as divided into the *air section* and the *fuel section* (Fig. 108). The air section is divided into chamber *A* and chamber *B* by the air diaphragm, equal in size to the fuel diaphragm which divides the fuel section into chamber *C* and chamber *D*.

Chamber *A* is connected to the impact tubes; it registers scoop pressure. Chamber *B* is connected to the boost venturi; it registers venturi suction. The pressure difference between the two chambers is a measure of the volume of the air flow and, when corrected by the automatic mixture control, it is a measure of the mass (weight) air flow through the carburetor. The pressure difference between chambers *A* and *B* acting on the air diaphragm produces a force to the right, tending to open the fuel valve. This force is termed the *air-metering force.*

To understand the functioning of the fuel section a few simple facts must be kept in mind. The rate of fuel flow from one compartment to another is dependent upon the difference in pressure between the two compartments and the size of the opening between the two compartments. The greater the pressure difference or the larger the opening the greater the fuel flow will be. The spray nozzle unit is the constant-pressure type and maintains a constant pressure of approximately 5 lb per sq in. in chamber *C*. The main supply pressure entering chamber *D* through the poppet valve is 12 to 15 lb per sq in.

As fuel enters through the poppet valve it fills chamber *D*, the fuel



Courtesy Bendix Products

FIG. 108. Schematic diagram of the Bendix Stromberg injection carburetor.

control body, and chamber *C* successively. When the fuel reaches the spray nozzle and the pressure at the nozzle rises to 5 lb per sq in., or to the pressure corresponding to the nozzle spring setting, discharge begins. Any flow through the metering jets in the fuel control body is accompanied by a decrease in pressure difference between chambers *D* and *C*. The pressure difference between chambers *D* and *C* acting on the fuel diaphragm produces a force to the left, tending to close the fuel poppet valve. This force is termed the *fuel-metering force.*

The air-metering force, from the air section of the regulator unit, controls the fuel-metering force in the fuel section of the regulator unit. When the air-metering force increases, the diaphragm assembly moves to the right, opening the poppet valve and increasing the flow of fuel through the poppet valve into chamber *D*. This increases the pressure in chamber *D*, with a resulting increase in metering pressure across the jets in the fuel control unit.

When the air-metering force decreases, the diaphragm assembly moves to the left, closing the poppet valve and resulting in a decreased pressure in chamber *D* and metering pressure across the jets in the fuel control unit.

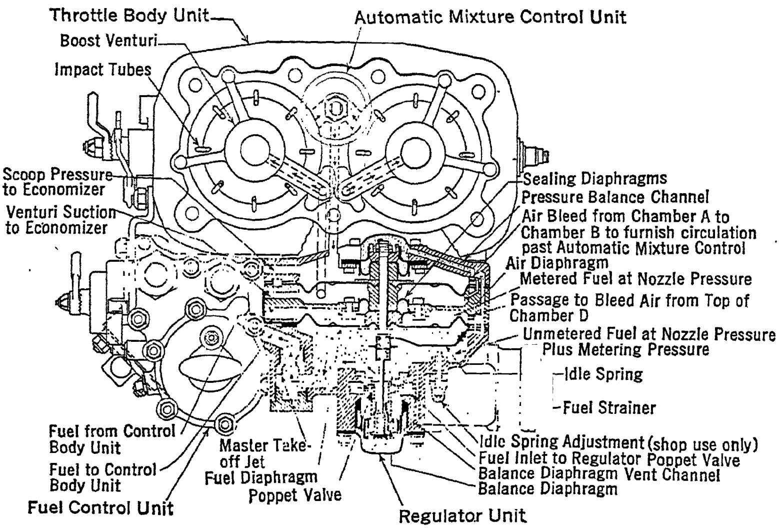
As an example, assume that the air flow through the carburetor is such as to produce a pressure difference of ½ lb per sq in. between chambers *A* and *B*. This air-metering force is transmitted to the fuel section and produces a metering pressure of ½ lb per sq in. on the fuel diaphragm. (Pressure in *D* will be ½ lb per sq in. higher than in *C*.) The fuel quantity flow from the fuel control unit will then be that delivered through the metering jets under ½ lb differential pressure. If the spray nozzle spring is set to hold the pressure in *C* to 5 lb per sq in. the pressure in *D* will be 5½ lb per sq in.

The flow rate is independent of nozzle pressure. If the nozzle spring compression should be increased to give 10 lb per sq in. in *C*, the pressure in *D* will go to 10½ lb per sq in. and the fuel flow rate will remain unchanged.

The air and fuel sections of the regulator are assembled as one unit. In addition to the fuel and air diaphragms, a pair of smaller opposed sealing diaphragms are used to avoid unbalance between the air and the fuel system pressures. A small balance diaphragm is also used on the poppet valve. All the diaphragms, the spacers, and the poppet valve are assembled on one stem and move as a single element.

Idling System. During idling conditions the metering force derived from the air diaphragm is not sufficient to open the poppet valve. Therefore, an idle spring is used to hold the poppet valve open for fuel

flow and metering pressure at idling. This spring is set during assembly of the carburetor to give an excessively rich mixture during idling. After the carburetor is installed on the engine this spring should not be used for adjustment. Final idling adjustment is obtained by adjustment of the contoured idle needle valve in the fuel control unit. This needle valve is connected by suitable linkage to the throttle valve so that it is completely opened at about 10 degrees of throttle opening.



Courtesy Bendix Products

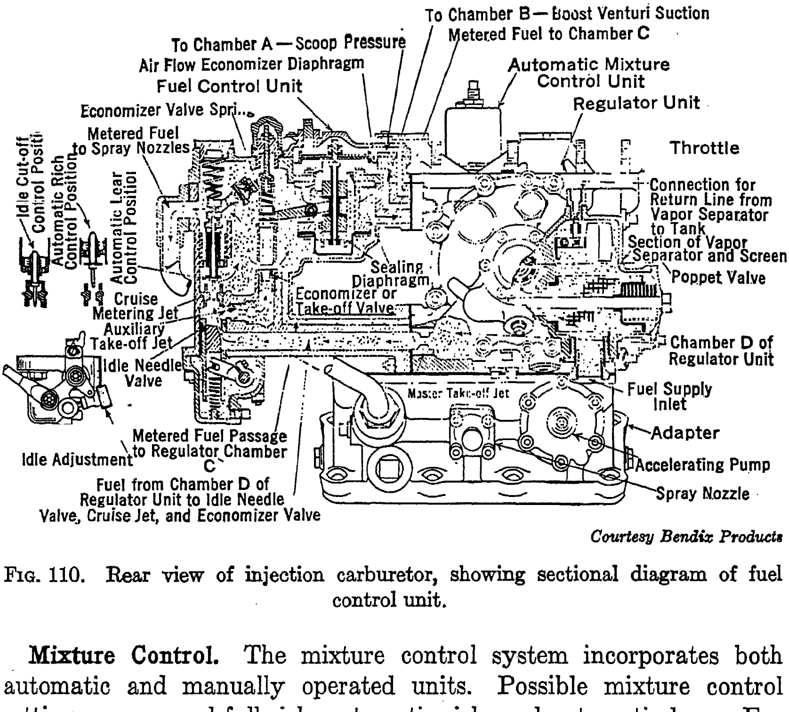
Fig. 109. Top view of injection carburetor, showing sectional diagram of regulator unit.

The fuel flow during idling may be readily traced on diagram of Fig. 108. Metering is accomplished by the idling needle until it opens sufficiently to give an area opening equal to the area opening of the cruise jet. As the idle needle area opening then continues to increase, the metering is accomplished by the cruise jet.

Economizer. To obtain the enrichment of mixture as the engine approaches full power an economizer valve operated by a diaphragm against a calibrated and preadjusted spring is utilized. The diaphragm is acted upon by the pressures in regulator chambers A and B of the regulator unit, which pressures are proportional to the mass air flow rate. The movement of the valve is therefore proportional to the air flow to the engine. The rate of enrichment with increasing power is determined by the taper on the economizer needle and the econo-

mizer valve spring. The maximum enrichment is determined by the size of the *master take-off jet.*

Some models of this carburetor utilize the difference in pressure between the fuel chambers C and D to operate the economizer valve. This design is referred to as the *fuel head enrichment valve.* The principle of operation is exactly the same as in the *air flow economizer* design. It differs in construction in that the needle moves directly with the one operating diaphragm, instead of through a lever system as in the air flow economizer.



Courtesy Bendix Products

FIG. 110. Rear view of injection carburetor, showing sectional diagram of fuel control unit.

Mixture Control. The mixture control system incorporates both automatic and manually operated units. Possible mixture control settings are manual full rich, automatic rich, and automatic lean. Except during manual full rich, the fuel-air mixture ratio is held automatically by utilization of the same kind of automatic mixture control unit as discussed under float-type carburetors (page 95).

Adjustment of mixture for changes in air density is accomplished by the automatic mixture control unit changing the pressure in chamber A, so as to change the A minus B difference in pressure, which is the metering head on the jets (Fig. 108). To achieve this, the pressure in chamber A is balanced between a small control suction vent at the bottom which leads from A to the venturi suction space B, and a larger

passage which leads to the impact tubes. The automatic mixture control unit is installed in the passage leading to the impact tubes. As the density of the air entering the air scoop is reduced by increase of altitude, the automatic mixture control bellows expands, lowers the valve point, and reduces the pressure in chamber *A*. The reduction of pressure in chamber *A* reduces the effective metering force with subsequent reduction of fuel flow to maintain a constant fuel-air mixture ratio. It must be remembered that fuel-air ratio is pounds of fuel per pound of air and that, as air density decreases, a pound of air passing through the carburetor requires more volume flow; also, that the suction created at the venturi, for fuel-metering purposes, is proportional to the volume air flow and not the mass (weight) air flow.

When the mixture control is placed in the *automatic lean* position the manual control needle (Fig. 108) is projected into the cruise jet orifice, thus reducing its effective area. When in the *automatic rich* position the manual control needle does not obstruct the cruise jet orifice. By manual selection the pilot is given the choice of two automatic mixture settings: the *automatic rich,* which is the leanest mixture that will be safe under all cruising conditions, and the *automatic lean,* which is the leanest mixture that is advantageous to use under the most favorable operating conditions.

In the manual full rich position the automatic mixture control unit is by-passed by opening the valve shown directly under the control unit in Fig. 108. Opening this valve connects chamber *A* directly with the impact tubes, resulting in maximum air-metering force. The cruise jet is, of course, not obstructed by the manual control needle when in the full rich position.

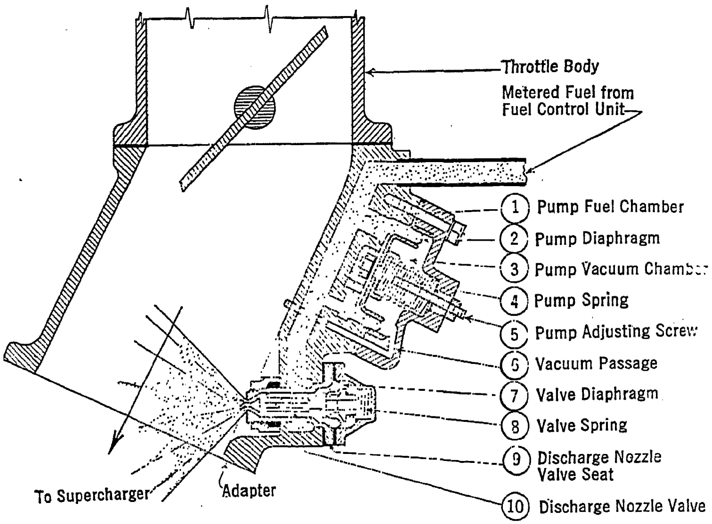
It will be noted that two locations are shown for the *take-off* jet. When the auxiliary take-off jet (dotted in Fig. 108) is used, the master take-off jet may be omitted. In this event, the manual control will give a change of mixture ratio at both cruise and take-off power. If it is desired to hold the take-off mixture ratio constant while the cruise ratio is varied, the auxiliary take-off jet is omitted and the master take-off jet is employed.

Instead of employing the manual control needle some model carburetors employ two cruise jets of different size to provide the automatic lean and automatic rich control settings. During automatic lean operation only one of the cruise jets is open, whereas both are open during automatic rich operation.

Idle Cut-Off. Idle cut-off for stopping the engine is obtained by moving the manual mixture control to the extreme limit of its travel. This depresses the mixture control needle until a disc valve strikes the

top of the cruise jet (Fig. 108) and cuts off all fuel flow except that through the very small orifice venting the top of chamber D to C. This flow is insufficient to run the engine.

Accelerating Pump and Discharge Nozzle. Metered fuel from the fuel control unit is conducted through a passage to the spray nozzle



Courtesy Bendix Products

FIG. 111. Diagram of injection carburetor adapter with single-diaphragm acceleration pump and spray nozzle.

and accelerating pump. The discharge nozzle is constructed with a diaphragm so that the fuel pressure is the main force tending to control its opening area. This type of construction allows a constant fuel pressure discharge without appreciable effect by vacuum or rate of fuel discharge. When the pressure on the nozzle diaphragm reaches 5 lb per sq in., or the pressure at which the nozzle spring is set to open, the force of the spring is overcome and the nozzle opens and discharges fuel. The nozzle will remain open as long as the pressure does not drop below 5 lb per sq in.

The single-diaphragm accelerating pump (Fig. 111) is automatically operated by vacuum. A passage (6) leads below the throttle valve to the pump vacuum chamber (3). The pressure difference between the pump fuel chamber (1) and the pump vacuum chamber (3) acting on the diaphragm (2) produces a force which moves the diaphragm "outward" on a suction stroke, compressing the spring (4). Fuel is drawn from the nozzle passage through the pump passages, filling the

pump fuel chamber (1). When the throttle is opened the pressure is increased on the vacuum side of the diaphragm (2) in pump vacuum chamber (3). The spring pushes the diaphragm (2) inward on a discharge stroke and forces the fuel through the pump passages into the nozzle passage; this causes fuel to be discharged quickly through the spray nozzle.

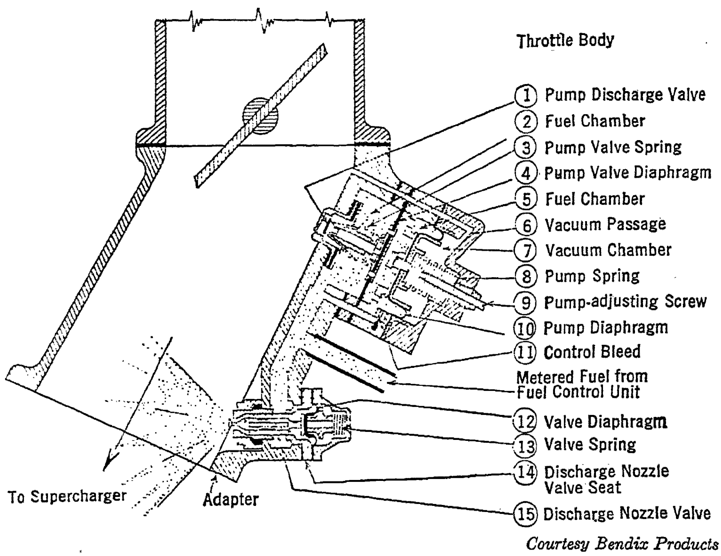
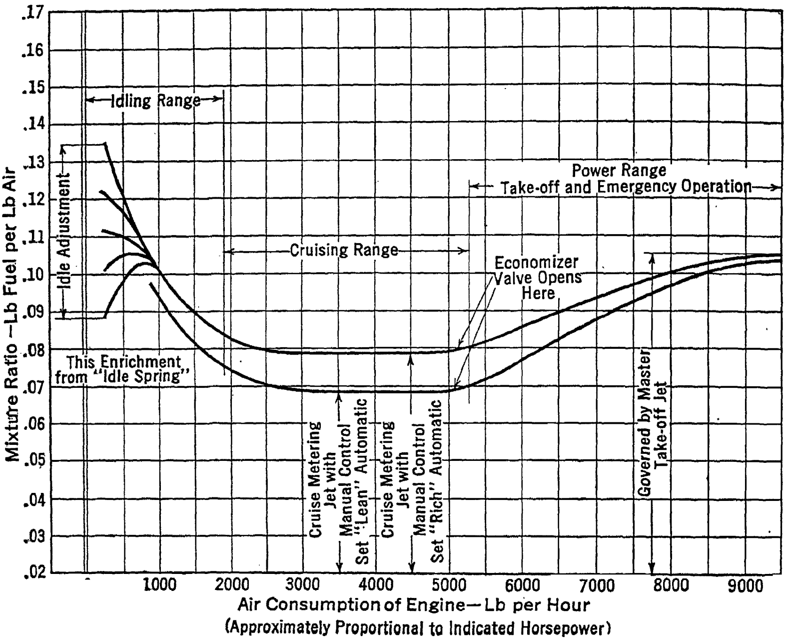


FIG. 112. Diagram of injection carburetor adapter with double-diaphragm acceleration pump and spray nozzle.

The double-diaphragm accelerating pump operates similar to the single-diaphragm pump, but is also provided with an auxiliary discharge (Fig. 112). When the throttle is opened the pressure is increased suddenly on the vacuum side of the diaphragm (10) in vacuum chamber (7). The spring (8) pushes the diaphragm (10), suddenly increasing the pressure on the fuel in fuel chamber (5). The pressure in chamber (5) produces a force on diaphragm (4) which overcomes the spring (3) and opens the discharge valve (1). The pressure on the fuel in chamber (2) increases suddenly, causing an accelerating discharge through the discharge valve (1) as well as an accelerated discharge through the regular nozzle. The fuel is forced out of fuel chamber (5) at a controlled rate through the control bleed (11). As the pressure in fuel chamber (5) drops, the discharge valve (1) closes and the diaphragms (4) and (10) return to the discharge position ready for the next suction application.

Vapor Separator. The vapor separator consists of a small vent valve in the top of the strainer chamber, held shut by a float, normally submerged in liquid fuel, which drops to open the vent when vapor enters the strainer chamber. The operation of the vent valve may be accompanied by a slight delivery of fuel. It is, therefore, recommended that a small return line be run from the vent valve to one of the fuel supply tanks.



Courtesy Bendix Products

FIG. 113. Typical fuel-air curve obtained with the injection carburetor.

Since the injection carburetor is a closed pressure system, it is necessary to make provisions for carrying off vapors from any chambers where a vapor lock might occur. A small orifice in the top of chamber *D* permits any vapor forming in that chamber to flow to chamber *C*, where it is carried to the discharge nozzle (Fig. 108).

MAINTENANCE

Installation. The specifications for jet sizes and operating characteristics of a carburetor are determined after many tests and hours of operation on the engine for which the carburetor is to be used. Thereafter the engine manufacturer denotes the specification of carburetor

to be used on particular engines. When installing a carburetor it is imperative that a carburetor of the correct specification be used. The specification will be stamped on the carburetor name plate.

The carburetor installation gasket is furnished by the engine manufacturer. It may be given a thin coat of sealing compound such as Fostoria to insure an airtight seal. Shellac is not soluble in gasoline; it constitutes a very good seal but makes removal of the carburetor very difficult.

When installing the carburetor controls one should make certain that they are permitted their full travel. Safety as required. Safety wires and devices on all plugs must be inspected. A sealing compound should be used when installing all pipe and tube fittings.

The fuel pressure requirements of the different types of carburetors are as follows:

Bendix Stromberg float type	2 to 4, preferably 3 lb per sq in.
Holley	6 to 7 lb per sq in.
Bendix Stromberg injection	12 to 15 lb per sq in.

Float-type carburetors to be used with a gravity head of less than 78 in. must be provided with special float needle valves and seats.

Float-type and diaphragm-type carburetors require no special instructions for filling when first used after installation. It is merely necessary to maintain an operating fuel pressure by means of the wobble pump until the carburetor fuel chamber has had sufficient time to fill.

To fill the injection carburetor the mixture control is set at automatic rich and the throttle half open. The fuel pressure is raised to 4 lb per sq in. with the wobble pump and the wobble pump is operated slowly until a small amount of fuel runs from the supercharger drain. A special condition exists when the carburetor is partly filled with air. The rate at which fuel may enter the second regulator chamber and the fuel control body is held to idling rate; this causes the carburetor to fill slowly. Since there are no vents in the system beyond the second regulator chamber, all included air must escape through the nozzle; this will cause the engine to stop. To eliminate this condition, the vent plug from the second chamber of the regulator is removed and the wobble pump is worked until the fuel stands level with the plug opening.

Idling Adjustment. The engine or airplane manufacturer will usually specify the correct idling speed. The correct idling speed will be one which does not induce excessive vibration. These speeds range from 400 to 600 rpm. The correct idling speed is attained by adjust-

ment of the idling speed adjusting screw on the throttle operating arm. Some carburetors are provided with an idling speed adjusting screw on both ends of the throttle valve shaft so that the throttle operating lever may be placed on either end. On such carburetors only the adjusting screw on the shaft end to which the throttle operating lever is attached is used. The other adjusting screw is backed well clear of the stop. Use of an adjusting screw on the opposite end of the shaft from the throttle lever will cause warping of the throttle shaft.

It is desirable to set the idle mixture to give the best power at the correct idling speed. It should not be set rich enough to cause the engine to "load up" when idled for long periods of time. On carburetors not equipped with mixture controls the idle mixture should be adjusted until all cylinders are firing evenly; then the throttle should be opened normally to give about 1000 rpm. Uneven firing during acceleration will indicate too lean a mixture or an insufficient accelerating charge of fuel. Throttle should be closed normally to make sure there is no tendency to stop.

Carburetors equipped with mixture controls may be checked for proper idle mixture setting in the following manner. Locate the idle adjustment at its midposition and allow the engine to idle until conditions are stabilized. Next, move the main mixture control lever to the lean position and note the change in engine speed. If the speed increases it is an indication that the idle mixture is too rich. Move the idle adjustment to a leaner position and repeat the check. If the speed definitely decreases it is an indication that the idle mixture is too lean. The idle setting is correct when there is a tendency for the speed to drop off slightly when the mixture control is moved from the *full rich position* to the *lean position.*

Another very excellent method for adjusting the idle mixture is to have one mechanic watch the manifold pressure gauge while another mechanic adjusts the idle mixture. The correct idle mixture adjustment will be the one giving the lowest manifold pressure reading.

Routine Service. In general very little attention is required between carburetor overhauls, which usually correspond with engine overhauls. Routine service and inspection at periods corresponding to engine inspection include the following:

1. Check tightness and safetying of nuts, bolts, and studs fastening carburetor to engine and air scoop.
2. Check all fuel and gauge connections for leakage.
3. Check parting surfaces of fuel section for seepage as evidenced by discoloration by fuel dye.

4. Check throttle and mixture control rods and levers for tightness and safetying.

5. Check throttle and mixture controls for freedom of movement, looseness of bearings, and excessive play.

6. In the *float type,* drain the float chamber. In the *Holley,* drain the diaphragm section, and clean out recess in drain plug; drain the diaphragm vent space and the accelerating pump section. In the *Bendix injection,* drain the regulator unit air chambers and fuel chambers, and the fuel control unit through plugs in bottom.

7. Remove and clean fuel strainers.

8. Replace all drain plugs and strainers and safety. Inspect for leaks with carburetor under operating fuel pressure.

Before removing drain plugs and strainer the fuel supply to the carburetor should be cut off. While the carburetor is being drained, it should be noted whether or not any water is being drained. If so, the complete fuel system should be checked for water. The fuel strainer may be cleaned by rinsing in clean gasoline and blowing with compressed air. Never use a wire brush for cleaning strainers, as it will damage the screen.

Trouble Shooting. In attempting to determine the reason for carburetor troubles one must first remember the fuel requirements of the engine and, second, the functioning parts of the carburetor which supply the fuel requirements of the different operating conditions, which are idling, acceleration, cruising, and full power. By localizing the trouble to one or more of the operating conditions, the pursuit of malfunctioning is reduced to particular functioning systems.

Carburetor troubles may be classified generally as mixtures too lean or mixtures too rich at one or more of the operating conditions. Too lean a mixture may be accompanied by backfiring, irregular firing, detonation accompanied by excessive cylinder head temperature, and excessive heating of the exhaust manifold because of slow burning of the gases. Too rich a mixture will cause a rolling, irregular running of the engine with blue exhaust smoke. Too rich or too lean a mixture will not allow the engine to develop its full horsepower. Hence, operation of the mixture control while the engine speed is being watched will indicate whether the mixture is too rich or too lean.

Several troubles external to the carburetor may give the same symptoms as carburetor troubles. Air leaks in the induction system between the carburetor and cylinders dilute the fuel-air mixture, especially at low speeds when the suction is high, and result in a lean mixture at the cylinders. Faulty ignition may give the same symptoms as a lean mixture, but can be recognized by the engine's missing locally

on one or more cylinders. Sticking valves, both intake and exhaust, give symptoms of a lean mixture. Preignition and mistimed ignition may cause backfiring by igniting the mixture while the intake valve is open. Poor compression within the cylinders gives a lean mixture symptom. The troubles just described, except for air leaks in the induction system, will not be cured by enriching or leaning out the mixture. Hence, their occurrence may be determined by watching the engine speed and operation while alternately leaning and enriching the mixture ratio.

Pistons pumping oil into the cylinders will give the same symptom as too rich a mixture, resulting in a rolling, irregular running of the engine with blue exhaust smoke. Running the engine at a speed above the idling range will clear out any excessive fuel in the induction system. After the engine is "cleared out" and operation is stabilized, the throttle should be closed slowly. If the engine immediately begins to miss after being slowed down it may be an indication of both too rich a mixture and oil pumping. The idling mixture should be adjusted and operation noted. If, after being slowed down, the engine runs for some time before missing, it is an indication that the mixture is satisfactory until it becomes saturated with oil.

Water is often found in gasoline. If it is present in the carburetor in sufficient quantity it may make the engine hard or impossible to start. Water is heavier than gasoline and unless there is sufficient quantity in the carburetor it may not be drawn through at the idling or lower speeds. This is especially true of carburetors which do not obtain the idling fuel from the lower portion of the fuel chamber. Water in the fuel will be carried through at the higher speeds and will cause rough operation and backfiring, a symptom similar to that of a lean mixture.

Some of the various types of carburetor troubles which may be encountered and their causes follow:

Float-Type Carburetors

1. Trouble: *Engine does not idle properly.*
   Cause:
   a. Idle adjustment not set correctly.
   b. Fuel pressure too high (too rich).
   c. Fuel pressure too low (too lean).
   d. Leaky or improperly adjusted float (too rich).
   e. Float needle valve sticking open (too rich).
   f. Air leaks in induction system. (Too lean. Not fault of carburetor.)
   g. Partially obstructed jet (too lean).

2. Trouble: *Idles properly. Too lean at cruising.*
   Cause:
   a. Main metering jet obstructed.
   b. Fuel pressure too low.
   c. Fuel supply line obstructed.
   d. Strainer dirty.
   e. Fuel chamber vent obstructed.
3. Trouble: *Engine does not accelerate properly.*
   Cause:
   a. Idling adjustment not correct.
   b. Mixture too lean at cruising range.
   c. Accelerating pump not operating properly or jet obstructed.
4. Trouble: *Too rich at cruising.*
   Cause:
   a. Fuel pressure too high.
   b. Leaky or improperly adjusted float.
   c. Fuel chamber suction nozzle obstructed.

Holley Carburetor

1. Trouble: *Engine does not idle properly.*
   Cause:
   a. Idle adjustment not set correctly.
   b. Air leaks between carburetor and engine.
   c. Metering needle sticking or metering pin lever springs broken or loose. Remove cover from righthand end and observe action as throttle is moved.
   d. Compensator needle leaking. Check by loosening the two screws which attach the compensator fuel line fitting to the compensator unit casting, applying a pressure of 6 to 10 lb by means of the wobble pump and watching for a leak at the fitting flange. If a leak is observed, remove compensator diaphragm and inspect needle and seat.
   e. Fuel supply inlet valves not seating properly. Apply 6 to 7 lb pressure with wobble pump and watch for leak at main discharge nozzle.
   f. Vapor separator sticking or leaking (Model H only). Apply 6 to 7 lb pressure with wobble pump and watch for leak at vapor-separator discharge.
   g. Idle fuel orifice in metering needle plugged (Model H only). Remove needle and inspect.
2. Trouble: *Engine runs too rich at cruising.*
   Cause:
   a. Metering pin sticking or metering pin lever springs broken or loose.
   b. Metering pin and/or metering pin cam improperly adjusted. Must be bench tested.

c. Main air bleed clogged. Remove scoop for access to top of carburetor. Remove air bleed cover screw, air bleed cover, and air bleed and inspect.

d. Compensator needle leaking. See 1*d* above.

e. Compensator valve spring weak or broken. Remove and inspect. Compare tension with known good spring.

f. Diaphragm unit flooding. Apply 6 to 7 lb pressure with wobble pump and watch for leaks at main discharge nozzle.

3. Trouble: *Engine runs too lean at cruising.*

Cause:

a. Mixture control disc halves separated or drive pin sheared. Remove end cap from mixture control housing and inspect.

b. Fuel pressure too low. Check by means of an accurately calibrated pressure gauge attached directly to the pressure connection on the carburetor. This pressure can be as low as three pounds without affecting the mixture at cruising power, but pressures below this will result in lean mixtures. In any event, if the pressure is not within the specified range of 6 to 7 lb required for all-round operation it should be so adjusted.

c. Air leaks into carburetor fuel passages. Inspect all parting surfaces, plugs, and connections for leakage.

d. Metering pin and/or metering pin cam improperly adjusted. See 2*b* above.

4. Trouble: *Satisfactory at cruising. Too rich at higher power.*

Cause:

a. Fuel pressure too high. See 3*b* above.

b. Main air bleed clogged. See 2*c* above.

c. Air leak between vent ring and carburetor main body. With scoop removed, check for loose or missing attachment screws.

d. Air leaking into diaphragm vent space. Check tightness of attachment of mixture control housing to main body and of the diaphragm vent space drain plug.

e. Diaphragm unit flooding. See 2*f* above.

f. Compensator spring weak or broken. See 2*e* above.

5. Trouble: *Satisfactory at cruising. Too lean at higher power.*

Cause:

a. Fuel pressure too low. See 3*b* above.

b. Turbulent flow of air into carburetor. Caused by loose backfire door on air scoop, air scoop being out of alignment with carburetor, or improperly designed air scoop.

c. Diaphragm vent and/or vent passages clogged. Check by removing the ⅛-in. plug from the mixture control housing and unscrewing the diaphragm vent restriction which is accessible when this plug is removed. Inspect the orifice for clogging and clean as required. Remove the ⅛-in. drain plug from the bottom of the space outside the diaphragms and check the passages for clogging by blowing

gently on a rubber tube applied to the drain opening. If the passages are obstructed, the diaphragm section must be removed and disassembled for cleaning. Do not, under any circumstances, use air for blowing out these passages while the carburetor is assembled.

d. Compensator spring tension excessive. See 2*e* above.

e. Compensator venturi suction passage clogged. After removing compensator valve spring nut apply a fuel pressure of not more than 1 lb to the carburetor. If the passage is clear, a small stream of fuel should flow out of the threaded hole.

f. Broken compensator diaphragm. Remove compensator cover and inspect.

g. Compensator venturi not seated properly. Remove fuel inlet fitting for access and check venturi for tightness of seating. A convenient method of checking is first to close the throttle and then to blow gently on a rubber hose applied to the mouth of the venturi. If there is any fuel remaining around the edge of the gasket, imperfect seating will be evidenced by bubbles or disturbance of this liquid.

6. Trouble: *Satisfactory at full rich. Too rich or too lean in cruising lean position.*

Cause:

a. Diaphragm vent restriction clogged or of wrong size. Remove ⅛-in. plug from mixture control housing for access to vent restriction. Unscrew and remove the restriction. If it is clogged or too small, the cruising lean mixture will be too lean. If the hole in the restriction is too large, the cruising lean mixture will be too rich.

b. Slot in mixture control disc clogged. This will make mixture too rich. Check by removing end plate from mixture control housing and inspecting disc. Blow out with air, if clogged.

c. Mixture control disc not seating properly. This will make mixture too lean. Clean and lap if necessary.

d. Passages in mixture control housing clogged. Remove housing and check.

e. Vent and/or suction passages in main body and diaphragm section clogged. Remove the mixture control housing, exposing the two openings to these passages on the mounting pad. Check the suction passages by blowing on the upper hole. Remove the ⅛-in. drain plug from the bottom of the space outside the diaphragm and check the vent passages by blowing gently on the lower hole. Both passages should be clear and unobstructed. Check the vent passages for leaks by replacing the drain plug and applying gentle suction to the lower hole on the pad. This passage should hold the suction.

7. Trouble: *Engine does not accelerate properly.*

Cause:

a. Engine does not idle properly. For good acceleration it is necessary that the engine first be adjusted to idle reasonably well.

b. Mixtures too lean in cruising range. Engine will not accelerate properly to any given rpm if the mixture at that rpm is too lean for satisfactory operation.

c. Accelerating pump check valve leaking or check valve spring broken. Remove ¾-in. hexagonal head plug in lower part of center section of diaphragm unit and inspect valve disc and its seat and spring.

d. Accelerating pump discharge nozzle leaking. Remove scoop and inspect nozzle. Lift the pump nozzle valve with the fingers and release. It should snap back on its seat. If not, the spring is probably broken. If any dirt is found, hold the valve open and flush with gasoline or kerosene, using an oil can. If found to be faulty it will be preferable to remove carburetor to replace nozzle.

e. Pump lock plunger stuck in shut-off position.

f. Pump diaphragm springs broken. Remove carburetor and remove diaphragm unit.

8. Trouble: *Engine does not shut off properly.*

Cause:

a. Mixture control disc parts separated or drive pin sheared. Remove end cap from mixture control housing and inspect.

b. Mixture control passages clogged.

c. Pump lock plunger broken or not seating properly. Remove the pump lock assembly and inspect for free movement of the plunger and condition of the leather washers.

d. Pump lock cam not properly set on shaft. The peak of the cam must be in line with the plunger when the mixture control lever is in the fuel cut-off position.

e. Diaphragm unit flooding. See 2*f* above.

f. Compensator valve leaking. See 1*d* above.

g. Vapor separator sticking or leaking. (Model H only.) See 1*f* above.

9. Trouble: *Engine runs too rich or too lean at cruising power with manual control in full rich (Model H only).*

Cause:

a. Dirt in main diaphragm vent. Remove plug and inspect.

b. Failure or incorrect adjustment of stabilizer valve. Remove and check on test stand.

c. Sticking or leaking vapor separator. See 1*f* above.

d. Suction or vent passage in main body clogged or leaking. Remove stabilizer valve, place thumb over one opening in side plate leading to dry side of diaphragms, and apply light pressure on the other. If there is a flow of air there is a leak. Remove thumb and apply slight pressure. If there is no flow of air, a passage is clogged. Check condition of gaskets.

10. Trouble: *Manual mixture control inoperative or inadequate, resulting in rich cruising lean mixtures (Model H only).*

Cause:

a. Power mixture valve stuck closed or partially closed. If stuck open, mixtures will not return automatically to full rich when

maximum cruise power is exceeded. Remove plug and check freedom of operation, shims, and spring.

b. Dirt in cruise lean vent restriction. Remove plug and inspect.

c. Passages leading to power mixture valve clogged or obstructed by gasket. Remove power mixture valve and inspect.

Stromberg Injection Carburetor

1. Trouble: *Engine will not start or continue to run after starting.*
   Cause:
   a. Insufficient fuel pressure. Check fuel pressure gauge.
   b. Idle adjustment too rich or too lean. Readjust idle needle.
   c. Air in regulator unit. Remove vent plug in top of unmetered fuel chamber *D* of regulator unit. Pump fuel until it stands level with plug opening.
   d. Check position of manual mixture control to see that control is not set in idle cut-off position.
   e. Main discharge nozzle sticking open. See that nozzles hold 3 lb pressure without discharging fuel. Otherwise, fuel will boil under high vacuum and will give erratic metering.
2. Trouble: *Engine runs too rich or too lean at cruising power.*
   Cause:
   a. Fuel pressure low. Check fuel pump and fuel pressure gauge. Clean strainer if pressure will not rise.
   b. Foreign material in cruise jet.
   c. Economizer needle leaking or stuck open. Remove bushing above needle for free motion or remove fuel control unit cover body to check needle and seat.
   d. Check automatic mixture control unit setting and bellows (if carburetor is running rich or lean in automatic position at altitude).
3. Trouble: *Engine runs too lean at take-off or rated power, but satisfactorily at cruising power.*
   Cause:
   a. Economizer valve binding. Remove fuel control unit cover body and check mechanism for freedom of movement.
   b. Insufficient fuel pressure.
   c. Check economizer opening point.
4. Trouble: *Engine runs too lean or too rich at altitude in automatic position, but satisfactorily at sea level.*
   Cause:
   a. Vapor separator float needle stuck in closed position. Remove strainer and inspect float for free movement.
   b. Automatic mixture control unit incorrectly set or malfunctioning. Remove this unit from carburetor and check travel and set per instructions.
   c. Manual mixture control valve set in wrong position. Check linkage to manual mixture control lever.

  d. Emergency full rich valve plates open or leaking. Remove valve cover on throttle body and see that slots in plates are open only in emergency full rich position, and that plates do not leak.

5. Trouble: *Engine does not accelerate properly, but runs satisfactorily with slow throttle movements.*

   Cause:

   a. Accelerating pump not adjusted to give required travel. Readjust.

   b. Fuel inlet to acceleration pump clogged at the intake restriction. Remove pump cover and diaphragms and examine.

   c. Discharge nozzle leaking.

   d. Fuel leak into air chamber in regulator unit. Remove air chamber drain plug.

   e. Suction hole to air side of accelerating pump diaphragm closed. Check to see that holes line up correctly.

6. Trouble: *Engine does not shut off in idle cut-off position.*

   Cause:

   a. Idle cut-off valve washer on mixture control needle not seating properly. Remove plug on side of fuel control unit adjacent to cruise jet to see if washer seats in idle cut-off position. Check control rods for full travel. Check for burr on metering jet.

   b. Economizer needle not seating properly. Remove fuel control unit cover body and check mechanism for freedom of movement.

   c. Check regulator unit for proper operation (poppet valve leaking).

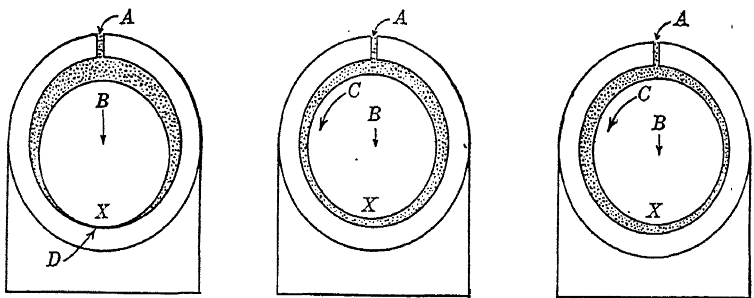
   d. In models with fuel head enrichment valve check mixture control plates for leakage, and check fill valve.

CHAPTER VI

LUBRICATION

Without some sort of lubrication it would be impossible to operate any type of machinery. It is not often realized, but the function of the lubricant in the internal combustion engine is to do more than merely lubricate. Besides lubricating, the lubricant must also cool, seal, and scavenge. The substance which has so far proved superior in doing all of these things is mineral oil, obtained from the refining of petroleum. In the future, synthetic substances may be developed which will do the job better than the mineral lubricating oils. They are already being used with mineral oils, in concentrations of from 0.1 to 3 per cent at present.

Lubrication. The object of lubrication is to reduce the power required to overcome friction resistance and to decrease the wear of rubbing surfaces. All surfaces, no matter how smooth they may appear to the eye, are rough enough to offer resistance to rubbing. A lubricant will make a surface slippery, and thereby reduce friction. There is no



(a) (b) (c)

FIG. 114. Lubrication of a journal bearing.

simple answer to what makes an oil slippery, but the degree of slipperiness varies with different oils. A good lubricant must have the ability to adhere to the surface to be lubricated. It must also have the ability to maintain a film between the rubbing surfaces. This ability to maintain a film between two surfaces in motion is sometimes referred to as film strength.

An illustration of the lubrication of a journal bearing is shown in Fig. 114. At view (*a*) the journal *X* is at rest. A vertical load *B*

causes a metal-to-metal contact with the bearing at point D. Oil which is fed in at A fills the space between the journal and the bearing. At view (b) the journal has begun to rotate in the direction of the arrow C. Oil adheres to a revolving journal and as speed is developed the oil forms a wedge which forces the journal and bearing apart. If a steady load B continues to bear down on the journal and the speed becomes stable, the forces of the wedge action and the load B will seek an equilibrium. The equilibrium position of the journal may be that shown in view (c).

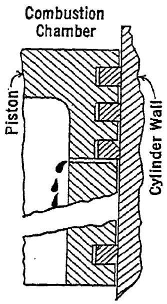


FIG. 115. One arrangement of piston rings to aid lubrication of the cylinder walls.

In the aircraft engine there are few if any steady loads such as B. In the reciprocating parts the loads change with every change in direction of motion. This change in load may be considered an advantage. While the load is forcing the journal toward a contact with the bearing the lubricant forms a relatively thick film on the opposite side of the bearing. Then, when the load is reversed, there is a relatively thick film of oil between the journal and bearing to take the new load.

Pistons are sometimes slightly tapered at their ends to allow a wedge action of oil between the piston and the cylinder walls. One method of aiding the lubrication of pistons through piston ring arrangement is shown in Fig. 115. The bottom ring scrapes oil upward along the cylinder walls. The second and third rings from the bottom scrape the oil downward to prevent excessive entrance of oil into the combustion chamber. The holes under these rings drain excessive oil back into the crankcase.

Ball bearings, roller bearings, and gears must force all oil but a very thin film from between their contacting surfaces. Therefore, excessive lubrication of these parts is detrimental rather than helpful. These parts are generally lubricated only by the oil mist within the engine.

Cooling. Because of thermal inefficiency all heat supplied to the engine by the combustion of fuel is not converted into work. The heat which is not converted into work must be carried away from the engine to prevent it from becoming excessively hot. The majority of the unconverted heat is carried away by the exhaust gases. Of what remains the most part is carried away by the main cooling system, be it liquid or air. Some heat, though, must be carried away by the lubricating oil. The pistons, especially, are dependent upon the lubricating oil for their cooling.

Besides a part of the unconverted heat of combustion, the lubricating

oil must also carry away other heat. Bearing friction creates heat which must be carried away by the lubricating oil.

To be a good coolant and withstand the high temperatures to which it is subjected, a lubricating oil must resist destruction or serious damage by heat. Also, it must not boil or readily evaporate at the temperatures to which it is subjected, or else it will soon all boil away.

After the oil has absorbed heat from the engine parts, the oil must be cooled if it is to continue as a cooling agent for the engine. This is done by circulating the oil through an air-cooled radiator or, as in some low powered engines, back into the sump where cooling takes place.

Sealing. Sealing is required in the engine to prevent leakage of the gases in the combustion chamber past the piston. Two metal surfaces are never perfect. There is always some leakage between two bare metal surfaces. In addition, to allow for the unequal expansion of the pistons and cylinders as the engine becomes heated and to provide space for an oil film, there must always be a clearance space between the pistons and the cylinder walls and between the rings and their grooves. An oil film can create a seal by effectively filling these clearances.

Scavenging. Dirt, carbon, and waste particles are constantly being picked up and circulated by the lubricating oil. Some of the contaminants, such as carbon, dirt, lead compounds, water, and unburned gasoline, enter from the combustion chamber by leakage past the piston. Other contaminants, such as dirt, water, carbon, and metal particles, enter through or are formed in the crankcase section. Still other contaminants are formed by the oil itself.

It would be desirable if all contaminants could be held in suspension by the oil and filtered or centrifuged out as the oil is circulated. However, many of the contaminants are readily soluble in the oil, and no practical method has so far been developed to prevent or remove these soluble contaminants. Filters and centrifuges are used for removing the larger solid contaminants. To remove the smaller solid particles filters have so far not been of very much practical value because of either their size or the pressures necessary for forcing the oil through them. However, experiments now under way indicate interesting possibilities in this connection.

Bearing surfaces which are successfully separated by an oil film are worn only by the solid particles which are thicker than the oil film. When it is realized that an oil film only four-millionths of an inch thick is necessary for good lubrication, it may be seen that the size of a solid suspended in the oil does not have to be large to cause wear.

As the oil continues to collect contaminants, especially those which it creates and dissolves itself, it reaches a point where the rate of self-contamination increases rapidly. Before this point is reached and before the solid contaminants become excessive, the oil must be drained from the engine and replaced with new oil.

Changes within the Oil during Engine Operation. In many machines, particularly those which do not expose the oil to combustion, oil may be used for a number of years without an appreciable change in its original properties. In the aircraft engine, however, oil must withstand more than a simple rubbing action. High temperatures, oxygen, extreme pressure, and a number of forms of contamination sooner or later change the clear, viscous liquid into a black, sticky mass. Not only does it change in appearance, but it also changes chemically; one form of this chemical change is called oxidation.

Heating and agitating oil in the pressure of an ample supply of air speeds up the oxidation of oil. Oil in the crankcase of an engine is broken into a fine mist as it is thrown from the rapidly moving parts. It is poured over hot metal surfaces and virtually "cooked" on the pistons, cylinder walls, and other engine parts. Under these conditions of heating and mixing with air, even the most stable oils will eventually oxidize to some extent. Some oils are able to resist oxidation better than others. Oil molecules may be classified in two general groups: those that are stable (less susceptible to the damaging influence of heat and air) and those that are unstable (more susceptible). Unfortunately, an oil which is made up entirely of the stable molecules apparently does not have the necessary slipperiness to lubricate well. For this reason, it seems that an oil must have some of the less stable compounds in order to be well balanced.

The products formed by oxidation do more than merely discolor oil, more than merely produce engine deposits; they hasten the oxidation of the remaining oil. The products of oxidation act as catalysts (aids) which accelerate the action of air on the oil.

Another chemical change which takes place in lubricating oil in an engine is known as polymerization. Under proper conditions of temperature and pressure, especially with metal present to act as a catalyst, two or more molecules may be joined together to form a new molecule of entirely different physical and chemical characteristics. Thus, briefly, polymerization of lubricating oil is the joining together of two unstable compounds to form solids, semisolids, or liquids of a different nature than either of the materials from which the formation originated.

The products of oxidation and polymerization of lubricating oils may

be divided into two classifications: first, those which stay mixed with the oil, and second, those which separate out and are deposited on the surfaces of the engine. Of all the contaminants that stay mixed with the oil after formation, the most attention is probably given to the acids. The temperatures and nature of the metals with which the acids come in contact are factors of its corrosiveness. The dividing line in either temperature or acidity at which corrosive action will occur has not been definitely established. The laboratory test for acidity does not directly indicate how harmful the contaminants in an oil may be. To determine this, the kind of acids present, the amount of each, the metals upon which corrosion is in question, and the temperatures attained would need to be known.

There are other products formed by chemical changes within the oil which do not stay mixed, but separate out, depositing in the various parts of the engine. One of the most objectionable forms of contaminants is a sticky material containing resins and asphaltenes. Combined with the water of condensation, the particles of partially burned fuel, dirt, and carbon, they form the black, sticky engine filth which is commonly called sludge. Deposits of this sludge will be found throughout the engine. One place where the sludge is particularly objectionable is in the piston ring grooves. A sufficient amount of sludge in these grooves will restrict the in-and-out movement of the piston rings and result in blow-by of the gases from the combustion chamber. The extremely high temperatures of the pistons and the particles of partially burned fuel from the combustion chamber aid the deposit of sludge in the piston ring grooves. It is often necessary to disassemble an engine long before overhaul is otherwise necessary because of sticking piston rings and carbon deposits within the combustion chamber and around valves. Some of the carbon deposits within the combustion chamber and around the valves and valve stems are caused by partially burned fuel. Partially burned lubricating oil which has entered the combustion chamber aids in this carbon deposit, the amount of deposit being increased considerably by a piston which pumps oil into the combustion chamber. Carbon deposits within the combustion chamber have a heat-insulating effect and tend to raise the temperature inside the cylinder. Overheating and subsequent preignition may result. The space occupied by the carbon deposits reduces the combustion chamber volume; this results in a higher compression ratio. The increased compression ratio and higher temperatures cause detonation, often referred to as "carbon knock." Fortunately, carbon deposits will not form indefinitely in the combustion chamber. An equilibrium will be reached when enough has been formed so that the insulating effect of the deposit

causes sufficiently high temperatures to burn off any more tending to deposit.

Water, which is one of the products of combustion, is constantly entering the crankcase with the gases which blow by the piston. Additional water is added from the moisture contained in the air breathed in through the crankcase ventilator. If the engine is operated continuously at high temperatures, this moisture may evaporate as fast as it is accumulated. However, frequent starting and stopping and low temperature engine operation, particularly in cold weather, invite excessive water in the oil, because more water condenses each time the engine cools off. Since the mixture of oil and water is continually agitated in the crankcase, the water remains in suspension in the oil, forming an emulsion. This emulsion gathers and combines with the carbon, dirt, and metal particles to accelerate the formation of sludge deposits. Water also aids in the formation of acids and other chemicals. Excessive foaming is brought about by the presence of water.

Water is not the only substance which blows past the pistons. Visible evidence that numerous gases enter the crankcase from the engine is shown by the smoke which continuously curls from the crankcase breather of an engine in operation. Carbon particles, in the form of soot, are continuously carried into the oil by these gases. These carbon particles are largely responsible for the black color of used oil. The grayish color of some used oils is caused by the blow-by of lead which may be traced to the lead compound which was in the gasoline to prevent detonation. The enormous amount of air which is used by the cylinders naturally brings a certain amount of dirt with it. Some of this dirt finds its way past the piston and into the lubricating oil. The presence of some of the contaminants may not be so detrimental mechanically, but the combination of these contaminants to form sludge and to act as a catalyst in the further chemical change of the oil becomes a vicious detriment.

The modern refiner is continually improving oils to build up their resistance to the deteriorating effects of the modern engine. Sometimes chemicals are added to increase the stability of an oil. Chemicals may be added to increase the oiliness and scavenging or washing ability of an oil. The addition of chemicals to improve one quality of an oil may destroy one or more of the other necessary qualities of the oil. Of course, the ideal chemical additive would be one which would improve all necessary qualities of an oil without diminishing any.

Engine Deterioration. Why do engines wear out? Why do parts break? Why do engines require disassembly and overhaul? All of these questions are closely related with the lubrication which an engine

receives during operation. An engine lubricated by an ideal lubricant suited to each of the rubbing parts and which kept all contaminants from the lubricants might still wear out or fail after long operation, but the operating life would be considerably longer than that of an engine not so lubricated.

Motion under load causes flexing or bending of the parts of the engine. Flexing or bending causes fatigue of the metal of which the parts are made. Fatigue of the metal results in breakage. Fatigue of metal may be imagined in almost the same sense as the word is used to describe the tiring of the human body. The difference is that nature provides the human body with recuperative powers to overcome fatigue. The fatigue of metal is cumulative until eventually breakage results.

Engine wear is due to the abrasive action of two contacting surfaces in motion when not completely separated by a clean oil film, or when separated by an oil film containing abrasives. Although sufficient clean oil may be present for proper lubrication, rubbing surfaces may actually come in contact with each other by forcing the oil film from between the surfaces. This may happen when excessive loads are placed on the bearing surfaces during high engine output. It may happen when the oil is so thin that it is not able to maintain a film between the rubbing surfaces. Operating at excessively high temperatures may thin the oil to a point where it cannot maintain a sufficient film. It may happen when the complete load is placed on only part of the bearing surfaces because of warping or deflection of the bearing surfaces. Uneven heating and uneven loading will cause warping of the bearing surfaces. Quick warm-up may result in uneven heating of bearings, warping, and consequent contact of the metal surfaces. Manufacture and installation of bearing surfaces which do not coincide will place excessive loads on parts of the bearing surfaces. If an engine is warmed up too quickly the piston will expand faster than the cylinder. If the expansion of the piston is great enough, there will not be sufficient clearance for an oil film. Excessive wear and heat will result. The piston may even seize. If the oil is so thick that it cannot readily penetrate the bearing clearances, insufficient lubrication will result. Until the oil is heated sufficiently to make it thin enough to penetrate all clearances, it does not lubricate properly. Therefore, it is imperative that the engine be warmed up at a low power output until the oil is up to operating temperature.

The majority of wear in the well-designed engine, when operated properly, is due to the abrasive contaminants in the lubricant.

As wear occurs, greater flexing and bending are allowed in the moving parts. This brings about more rapid fatigue, which results in earlier

failure of the parts. As wear increases the clearance between bearing surfaces, more oil can be pumped throughout the lubrication system per unit of time. Excessive oil is not desirable in the crankcase of high speed engines.

Extra high speed operation causes increased temperature, which more rapidly destroys the lubricant intended to prevent the abrasion that results in wear, thus accelerating mechanical deterioration. High speed operation, as previously mentioned, also puts exceedingly heavy loads on the bearing surfaces which may force the oil film from between the surfaces.

To check the wear of the rubbing surfaces, aircraft engines must be completely disassembled at regular intervals. Where wear is excessive for continued proper operation, parts are replaced. Of course, while the engine is disassembled all parts are inspected for cracks and other faults, but disassembly for this inspection could be long delayed were it not for wear of the bearing surfaces. The deposits of sludge in piston ring grooves, on valve stems, and elsewhere sometimes necessitate the disassembly of engines for cleaning before wear would necessitate the disassembly.

Properties of an Oil. No one oil can be expected to do a perfect job of cooling, lubricating, sealing, and scavenging at all points of the engine simultaneously. Hence, a lubricating oil must be a compromise. Some of the properties of an oil, as given in the usual specification, have some value in determining the suitability of an oil to perform the functions of cooling, lubricating, sealing, and scavenging. However, the importance of these properties should never be overestimated, and it should always be kept in mind that the lubricating oil has not just one, but four jobs to perform. The laboratory test used to determine the properties of an oil seldom simulate the conditions within the engine. Hence, an actual test in a full scale engine is actually the only way to determine definitely the suitability of an oil for a particular engine.

The *gravity* and *color* of an oil have no relation whatsoever to the ability of an oil to lubricate, cool, seal, or scavenge.

The *pour point* of an oil indicates the lowest temperature at which the oil will perceptibly flow from a receptacle without assistance. It does not necessarily indicate, though, the lowest temperature at which the oil may be pumped, provided the pump is primed. It is an indication of the temperature at which the oil will congeal enough to stop its flow or pouring ability, provided it is not agitated.

The *flash* and *fire points* are laboratory tests which show the temperatures at which the oil will begin to give off ignitable vapors (flash) and sufficient vapors to support a flame (fire). Their inaccuracy as an

indication of the rate of oil consumption in an engine lies in the fact that they only furnish a rough measure of the initial boiling point of the oil without showing the boiling range or volatility. Barring leakage, the only two ways in which an oil can be "used up" by an engine are by the oil being burned or being evaporated.

The *carbon residue* of an oil is an indication of the amount of carbon produced when a given quantity of oil is decomposed by heat in the presence of a limited amount of air. It does not indicate the type of carbon formed. Soft, fluffy carbon will leave little deposit but hard, flinty carbon may be more injurious to the engine. A low carbon residue is desirable but, although it may indicate the amount of carbon formed by an oil, it does not indicate the amount of carbon which would be deposited by an oil in an engine.

The *neutralization number* of an oil is an indication of its acidity. It is measured by the number of milligrams of normal potassium hydroxide required to neutralize 1 g of the oil. It does not indicate the type of acid present, whereas some acids are very deleterious to engine parts and others have no harmful effect. Some compounding chemicals, such as oil-soluble soaps often used in diesel engine lubricants, may react with the potassium hydroxide like an acid, and oils containing these materials show a fictitiously high neutralization number. The neutralization number of an uncompounded oil before and after use in an engine is a good indication of the amount of oxidation that took place. However, it is not a reliable indication of the corrosiveness of the oil because the acids formed by the oxidation vary, some reacting readily with bearing metals and others being relatively inactive.

Viscosity is the resistance of an oil to motion (flow). The most commonly used method of measuring viscosity is the Saybolt Universal method. By this method, the viscosity or body of an oil is measured in terms of the time it takes, expressed in seconds, for 60 cu cm of oil to flow through a standard-sized orifice.

All oils change greatly in viscosity with changes in temperature, and for this reason two more things should be remembered in relation to viscosity: first, that the viscosity of an oil is generally measured at the standard temperatures of 100°F, 130°F, and 210°F; second, that all oils do not change as much in body, or, to put it another way, do not change in body at the same rate, between two temperatures. In other words, one oil may get thicker at lower or thinner at higher temperatures than another oil.

Broadly speaking, the lower the viscosity of an oil, the thinner that oil is, and the better it will flow over the engine parts to cool, scavenge, and penetrate into close clearances so as to be available for its lubri-

cating duties. However, such thin oils will not seal as well against blow-by. Alternately, the higher the viscosity, the thicker the oil is, and within reasonable limits the better that oil will seal, but in general heavier oils cannot penetrate into close clearances to cool, lubricate, or scavenge. As the viscosity of an oil increases, there is an increase in friction, but a lessened danger of rupture of the oil film. Conversely, as the viscosity decreases the oil becomes thinner and there is a decrease in friction, but the ability of the oil to maintain a film is decreased. Theoretically, for correct lubrication only, as thin an oil as will stay in place and maintain a film with a reasonable factor of safety should be used. Yet, since the oil must also seal, it is not possible to use as thin an oil in the aircraft engine as would be required only for lubricating. An oil of the correct viscosity for lubricating only would be so light that it would readily pass the piston and be consumed in the cylinder in large quantities. For proper sealing, aircraft engines require more viscous oils than automobile engines, owing to the greater clearance between the pistons and cylinder walls. The greater clearance in aircraft engines is necessitated by the higher operating temperatures, the high expansion coefficient of the aluminum alloy pistons, and, in many cases, by a piston of greater diameter than the average automobile piston. An oil sufficiently heavy to seal properly at operating temperatures will be very heavy and difficult to circulate at low temperatures. This is one of the main reasons for a careful warming up of the engine.

All mineral oils change in viscosity as they change in temperature. They become thinner as they get hot and thicker as they cool. The method of rating oils according to their change in viscosity within a given temperature range is called *viscosity index.* It is an arbitrary rating based on the viscosity change in two standard liquids between a specified temperature range. An oil which will change from a thick liquid to a thin liquid within a few degrees of change in temperature is said to have a very low viscosity index. An oil which changes very little in viscosity over a temperature range is said to have a high viscosity index.

The viscosity and viscosity index of an oil are criteria of the ease with which an engine can be turned over for cranking during cold weather.

The clearances between the bearing and other rubbing surfaces, the bearing pressures, the rubbing speeds, and the temperatures encountered in operation and the compromise of sealing, lubricating, cooling, and scavenging dictate the viscosity and viscosity index of the lubricating oil to be used in a particular engine.

Until tests have been perfected which will better indicate the ability of an oil to perform all its functions and to resist deterioration, it will be necessary to rely upon what help can be gained from the usual specifications, the integrity of the refiner, the recommendation of the engine manufacturer (based upon full scale engine test), and service experience. All engine manufacturers recommend the viscosity of the oil to be used in their engines. This may differ for winter and summer operation, more for the ease of starting than for any other purpose. Some engine manufacturers run full scale engine tests on oils of the various refiners and will recommend only those oils which come up to their standards for operation.

Given below are the general properties of an oil which one of the prominent engine manufacturers has found to be common in all oils that have proved suitable in service. The manufacturer emphasizes, though, that these properties are only of a general nature and that a given oil meeting these requirements is not necessarily satisfactory for use in their engines.

	Temperate	*Torrid*
Flash point	475 minimum	500 minimum
Viscosity (210°F Saybolt Univ.)	100 plus or minus 5 sec	120 plus or minus 5 sec
Viscosity (100°F Saybolt Univ.)	Not over 12.5 times viscosity at 210°F	Not over 14.5 times viscosity at 210°F
Viscosity index (Dean & Davis)	95 minimum	95 minimum
Pour test	10°F maximum	10°F maximum
Carbon residue	1.00% maximum	1.25% maximum
Neutralization number — new oil	0.10 maximum	0.10 maximum
Emulsion test	60 minutes maximum time to settle out using distilled water at 180°F	60 minutes maximum time to settle out using distilled water at 180°F

All the foregoing has no doubt impressed the reader with the fact that the mechanical condition of the engine and the manner in which it is operated, as well as the quality of the oil, have the greatest effect upon the oil's rate of deterioration and that, inversely, the changes in the oil react upon both the engine and the oil. Intelligent preventive maintenance practice and proper operation are salient factors controlling the vicious cycle.

Engine Internal Lubrication System. The internal lubrication system on all modern high output aircraft engines is the forced pressure feed dry sump type. Some of the lower powered and older types of

engines incorporate a wet or partially wet sump system. A wet sump system is one in which a level of oil is maintained in the crankcase and the oil is furnished to the engine parts by splash or forced circulation or a combination of both. A dry sump system is one in which the oil supply is carried in a supply tank separate from the engine. The oil is supplied to the engine internal lubrication system by a pump, usually incorporated in the engine, and circulated throughout the engine under pressure. Throughout the system leakage occurs at bearings, and leakage ports are provided to direct oil on certain parts, such as cylinder walls and valve cam mechanisms, which cannot be lubricated under pressure in the same manner as bearings. All return oil from the crankcase section, the front section, and the rear section of the engine drains into a sump. A pump, commonly called the scavenging pump, picks up the oil and carries it back to the external oil supply.

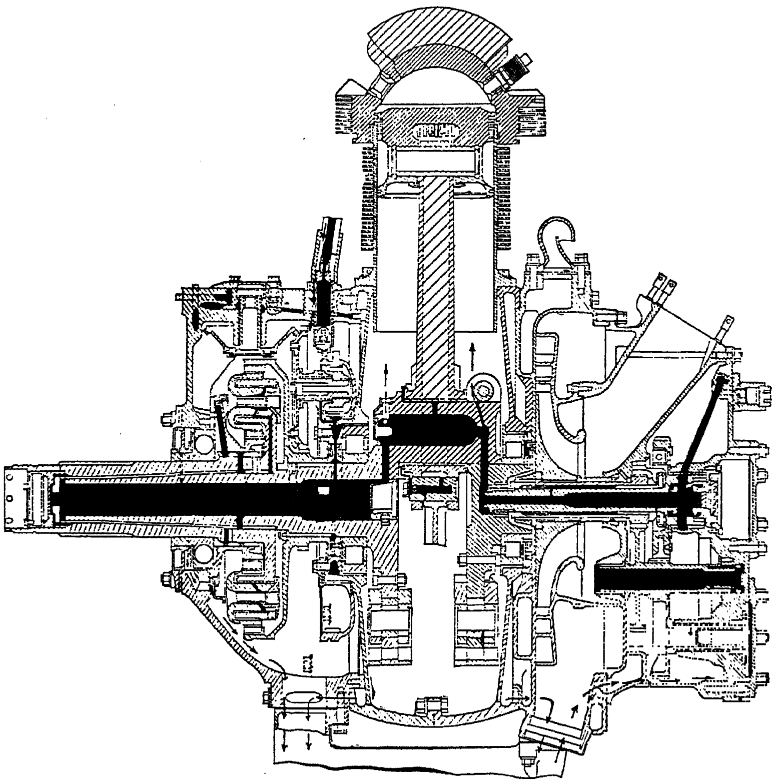
The necessity for dry sump lubrication may be appreciated by visualizing the complications which would result if a wet sump system were used in an engine which was flown in inverted flight, or mounted in an inverted position, which had cylinders around the circumference of the crankcase, such as a radial engine, or which had roller bearings, ball bearings, or gears immersed in oil.

Some very ingenious methods have been utilized to direct the crankcase section return oil to the sump under all conditions of flight. A description of these is beyond the scope of this book since they are more the concern of design than of maintenance. Suffice it to say that the oil does rather rapidly find its way into the sump.

The detail method of circulating the oil throughout the engine varies with different engines. It would be a long task to describe the detailed circulation of even one engine. A number of drawings would be required to show the circulation path to each part. However, as a good example of lubrication of the radial engine, a single view of the longitudinal section of the Wright GR-1820-G200 engine is shown in Fig. 116.

The lubrication system is the full pressure type except for the cylinder walls, the piston pins, and the crankshaft ball and roller bearings, which are lubricated by splash. The oil is supplied by an oil pump mounted on the left side of the rear cover. The oil pump, which is the gear type, is provided with a spring-loaded relief valve which lifts from its seat when the desired pressure is reached and delivers excess oil to the inlet side of the oil pump. Pressure regulation is accomplished by an adjusting screw which increases or decreases the tension on the relief valve spring. The pressure pump discharges the oil into a built-in filter. The filter, which is not shown, will be discussed later. From the filter the oil is conducted to and through the complete rear section.

An oil pressure gauge line is led off directly after the oil passes through the filter. Of course, there is some leakage around bearings in the rear section and there is some leakage through small holes provided to assure lubrication to parts other than bearings. All this leakage oil is directed back to the sump. To prevent external leakage at the rear



Courtesy Wright Aeronautical Corporation

FIG. 116. Longitudinal section through a Wright 9-cylinder, radial, air-cooled engine with reduction gear, showing internal lubrication system.

end of the accessory drive shafts, the shafts are equipped with oil seals. For accessories, which would be greatly damaged by the entrance of oil, an external drain is also provided so that any oil which might pass the seal will drain externally. The fuel pump drive shaft supporting bushings are made of an oil-soaked material and do not require pressure lubrication.

From the rear section the oil is conducted through the hollow center

of the accessory drive and starter shaft to a recess in the rear crankcheck, through the hollow crankpin, through a recess in the forward crankcheck, and thence forward through the crankshaft to the forward section.

A hole in the crankpin leads oil to the master rod bearing. Oil is also led to a recess between the master rod end seal and the forward end of the crankpin, whence a series of drilled passages in the articulated rod knuckle pin locking plate lead oil to the center of each knuckle pin. The knuckle pins each have two drilled holes which lead oil to the knuckle pin bushings. Small holes in the front and rear crankchecks throw out oil to lubricate the cylinder walls and piston pins. The leakage from the knuckle pin bushings also aids in lubricating the cylinder walls and pistons. If a seal is not provided for the master rod bearing, leakage from it will also supply the cylinder walls and pistons. The seal, which is present in this installation, assures an almost constant rate of flow to the cylinder walls and pistons through the holes in the crankchecks. If the seal were not present the rate of flow would increase with the wear and subsequent increased clearance of the master rod bearing. Between overhauls the clearance might increase so much as to give an undesirable amount of oil to the cylinder walls and pistons. The master rod bearing clearance tolerances must be held closer on engines without seals than on those with seals. Bearings with seals also insure an ever-present supply of oil under pressure throughout their length, whereas unsealed bearings leak oil from their ends.

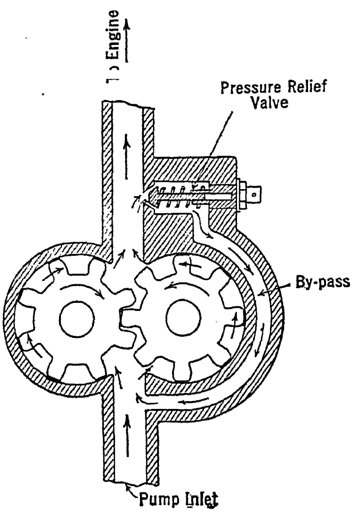


Fig. 117. Diagram of a gear-type oil pump with relief valve.

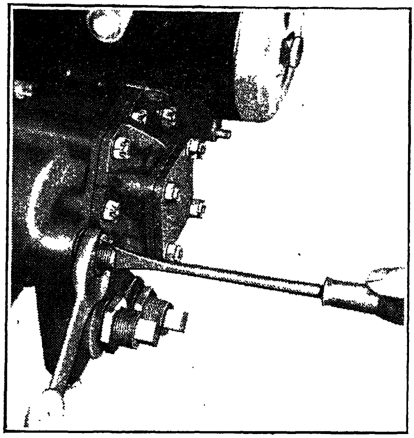
Through the hollow crankshaft the oil is led forward to the front section. Here it is distributed through passages to the various bearings. Small leakage holes provide lubrication to such parts as gears and the valve cam mechanism. A passage is provided up through the valve tappets and hollow push rods to the rocker arms and into the rocker arm bearings. Oil escaping from these bearings lubricates the valve stems. Return oil flows between the push rods and push rod housings.

Oil from the hollow crankshaft is also used to supply the propeller governor and the propeller.

All return oil drains to the sump. The front section return flow and the rear main return flow may be diverted for test purposes to obtain an accurate measurement of oil flow from the power section alone. Oil is withdrawn from the sump by the scavenging pump, not shown in Fig. 116.

It is easy to see that excess drainage on the system at any point, such as might be caused by a bearing with excess clearance, or restriction to flow at any point, will starve other parts of the system and result in improper lubrication.

Many of the older types of engines and some of the low powered engines are not provided with pressure lubrication for the valve and valve rocker mechanism. Such engines are lubricated by a relatively heavy oil or grease contained in the rocker box. A felt pad is generally installed in the rocker box to act as a wick. On some engines it is necessary to remove the rocker box covers to add the rocker box lubricant, whereas others are equipped with grease fittings which allow the use of a grease gun. It is usually necessary to lubricate the rocker boxes at intervals of from 5 to 10 flying hours.



Courtesy Wright Aeronautical Corporation

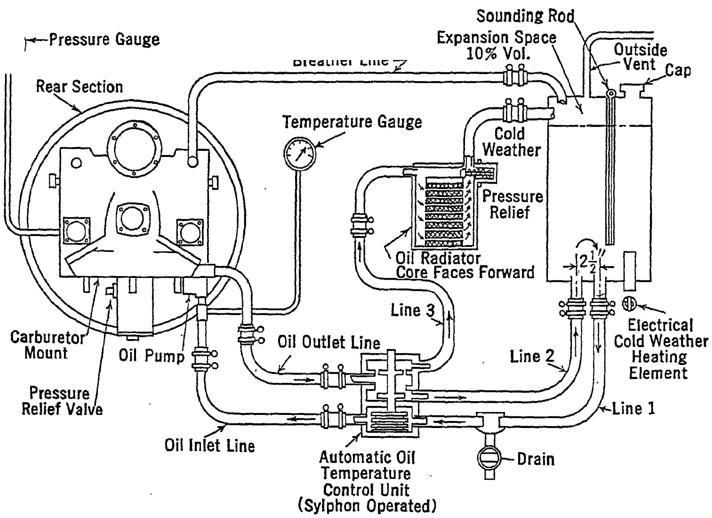
FIG. 118. Adjusting an engine oil pressure relief valve.

External Lubrication System. The function of the external lubricating system is to supply oil to the engine in the proper condition of temperature and viscosity under stabilized conditions. Proper lubrication immediately after starting is necessary. A reduction in the oil warm-up period is desirable. Any practical scheme which will allow ease of starting during cold weather is desirable.

The external lubrication system consists of a tank for holding the oil supply, a cooler (sometimes referred to as an oil radiator or oil temperature regulator), a strainer (if not provided within the engine), sometimes a control for directing the flow of different temperature or different viscosity oil, and the necessary tubing and connections for conducting the flow.

The Civil Aeronautics Administration requires that 1 gal of oil shall be carried for each 20 gal of fuel, and in no case shall less than 1 gal be carried for each 75 hp on the smaller engines. Requirements are based on the theory that there should be sufficient oil in the system to maintain proper cooling at the time the fuel supply is completely expended, even though the engine oil consumption is at a maximum.

A complete external system is illustrated in Fig. 119. The oil from the engine is directed into the automatic oil temperature regulator. The temperature of the oil passing from the supply tank to the engine (line 1) passes through one compartment of and operates a thermostatic valve in the automatic oil temperature regulator. When the oil



Courtesy Civil Aeronautics Administration

FIG. 119. Typical layout of an external oil system equipped with automatic oil temperature control, oil cooler, and electrical heating element.

in line 1 is cold the thermostatic valve directs the flow of oil from the engine into line 2 which empties into the oil supply tank very close to outlet line 1. The warm oil from the engine, entering the supply tank close to the outlet, is taken away at the outlet and carried back to the engine. With such an arrangement it is a matter of only a comparatively short time until a supply of oil hot enough for operating conditions is circulating. Only that oil which is circulated to the engine, and not the complete oil supply, needs to be up to the operating temperature. As the temperature of the inlet oil increases to or above the correct inlet temperature the thermostatic valve directs the engine

outlet oil through line 3 to the oil cooler. The oil is cooled in the cooler and is thence conducted to the main supply tank which it enters at a point not in close proximity to the outlet connection.

The action of the thermostatic valve is not sudden but gradual over a range of about 30 Fahrenheit degrees; that is, from some predetermined temperature through a temperature rise of 30 Fahrenheit degrees, the valve will go from a position where it is directing all the oil through line 2 to a position where it is directing all the oil through line 3. It will be seen, then, that part of the time oil is being directed through both lines 2 and 3. The operating temperatures of the thermostatic valve will be determined by the inlet temperature requirements of the engine. The thermostatic valve of a commonly used automatic oil temperature regulator operates its full throw between 140°F and 167°F.

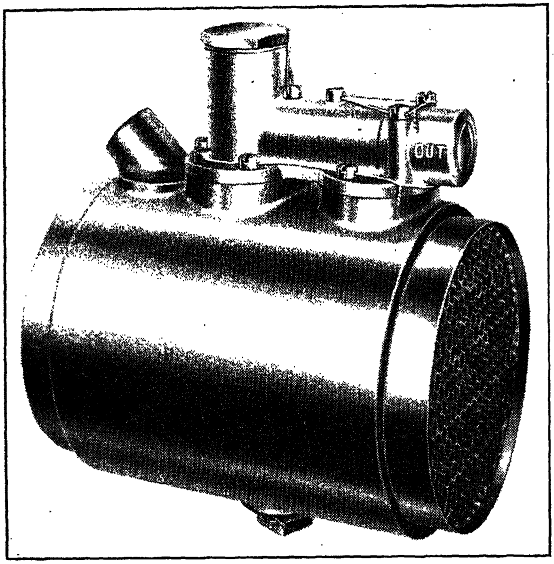
A suitable method is provided for determining the oil temperature at the engine inlet. Electrical resistor temperature indicators and thermal expansion indicators are both used for this purpose. Sometimes a temperature indicator is also provided for measuring the oil temperature at the engine outlet. A comparison of the inlet and outlet temperatures is a very good method of determining the functioning of the internal lubrication system.

All external lubrication systems have one or more drains at the lowest point or points of the system. The drains must be so placed that the system can be completely drained when the airplane is in its normal ground position.

Not all external lubrication systems are equipped with automatic oil temperature regulators as shown in Fig. 119. Neither do all systems place the oil cooler between the engine outlet and the supply tank. It is often placed between the supply tank and the engine inlet.

Oil Coolers. An oil cooler with a spring-loaded relief valve is shown in Fig. 120. The radiator is made up of a number of small tubes. The ends of the tubes are formed to a hexagonal shape slightly larger than the round portion of the tubes. These hexagonal ends are soldered together to form the core. Air passes through the inside of the tubes while oil fills the spaces between the outside walls of the tubes. Baffles are provided in the core to obtain a long path for the oil through the core. The core is completely covered with a cylindrical metal cover soldered in place. Around this cylindrical cover there is placed another cylindrical cover which provides a space between the covers known as the jacket. The flow through the radiator is shown in Fig. 121. The oil enters as shown and may flow either through the core or through the jacket. To flow through the jacket the oil must unseat the pressure relief valve. Therefore, unless too large a pressure is built up by the

flow through the core, the complete flow will be through the core and the relief valve will not unseat. Should, however, the viscosity of the oil in the core be so high that flow is difficult, the oil will pass through the jacket, which offers much less resistance than the core, and out through the relief valve. The flow of hot oil through the jacket will have a tendency to heat up the oil of the core and reduce its viscosity.



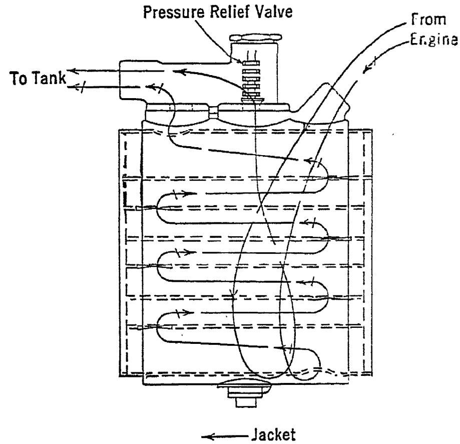
Courtesy United Aircraft Products

FIG. 120. Oil cooler with spring-loaded relief valve.

Fig. 122 illustrates the flow of oil through a cooler equipped with a thermostatic valve in place of the pressure relief valve. This cooler regulates the cooling on the basis of the oil-out-of-cooler temperature. Since the jacket is the path of least resistance, most of the oil will flow through it unless restricted. The thermostatic valve, which is regulated by the temperature of all the oil going out, restricts this flow through the jacket to give a constant outlet oil temperature.

The flow through a constant viscosity oil cooler is shown in Fig. 123. The oil first flows into the viscosity valve, which determines, by the viscosity of the oil, whether it should be cooled to increase its viscosity or directed through the jacket, where very little cooling will take place. The viscosity valve operates on a pressure differential principle. By conducting the oil through sampling tubes a difference in pressure caused by a difference in viscosity of the entering oil operates valves

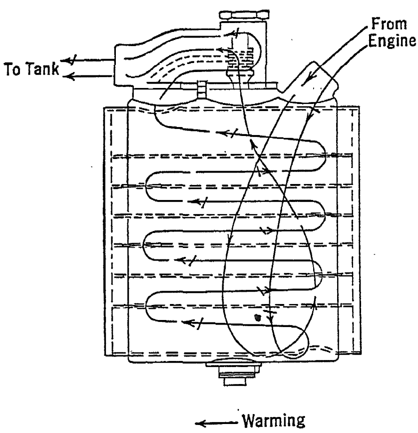
which conduct the oil through either the jacket or the core. The constant viscosity oil cooler will maintain the oil within a predetermined viscosity range regardless, within limits, of the standard viscosity rating of the oil. A heavy oil will, of course, have to be maintained at a higher temperature than a light oil. The proper lubricating quality is maintained since it is a function of viscosity and the viscosity is always maintained the same.



Courtesy United Aircraft Products

FIG. 121. Diagram showing the flow paths of oil through cooler with pressure relief valve.

Oil coolers which are not equipped with thermostatic valves or constant viscosity valves must be installed with shutters to regulate the flow of air through the core. Coolers with thermostatic valves or viscosity valves may or may not be installed with shutters.



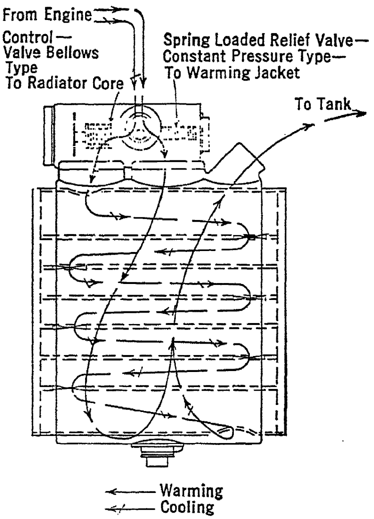
Courtesy United Aircraft Products

FIG. 122. Diagram showing the flow paths of oil through a cooler with thermostatic valve.

Oil Dilution, Quick Warm-Up Oil System. During very cold weather the viscosity of the oil within the engine becomes so high, while the engine is not running, that it becomes very hard if not impossible to turn over the engine. Fire pots, heating hoods, and other devices are used to warm the oil within the engine sufficiently to allow starting. Most of these devices have their attendant fire hazard. Immediately after the engine is started it is essential that a supply of oil be available for the lubrication of all parts. Cold, heavy oil cannot properly lubricate as it does not flow freely between the close clearances. It is undesirable

to have a long warm-up period to bring the circulating oil up to the proper operating temperature to insure correct viscosity.

The oil dilution system illustrated in Fig. 124 provides light oil for starting, light oil for circulation immediately after starting, and a short warm-up period by virtue of the small quantity of oil circulated and also its lower viscosity.



Courtesy United Aircraft Products

FIG. 123. Diagram showing the flow paths of oil through a cooler with viscosity valve.

The oil dilution system is based on the principle that, within practical limits, a cold oil will provide satisfactory lubrication when diluted to the proper lubricating viscosity by the addition of gasoline.

The system provides for thinning the circulating engine oil, prior to stopping, when cold weather starting is anticipated. As shown in Fig. 124, gasoline is introduced into the circulating oil by opening a valve connected to a fuel pressure line. Gasoline flows into the circulating oil stream and dilutes the oil. The length of time the gasoline valve is held open will depend upon the rate of gasoline flow, the amount of oil to be diluted, and the degree of dilution desired. Normal installations require that the valve be held open three or four minutes. The valve is operated from the cockpit either manually or electrically.

With the engine cold, starting will be easy, since it will have thin oil throughout. The thin oil also provides immediate lubrication after starting with an oil which can flow relatively easily.

It is undesirable to dilute the complete external oil supply. Also, it is desirable to circulate only a small portion of oil so as to shorten the warm-up time. To accomplish these two things, a special tank, called a hopper-type tank, is utilized. The construction of the tank may be seen in Fig. 124. The hopper is a cylindrical tube which extends from the top of the tank almost, but not quite, to the bottom of the tank sump. The capacity of the hopper is about 1½ gal. Oil coming from the engine enters the top of the hopper. The oil stream is directed tangentially and downward against the hopper wall. This aids in sepa-

rating the oil from the air and prevents the oil tank from foaming over. A large quantity of air is picked up with the oil by the engine scavenging pump. The oil flows through the hopper and out the tank outlet in the sump. Hence, it may be seen that only a small quantity of oil is actually circulated. It is only this small quantity of oil which is circulated that must be diluted and that must be warmed up to the

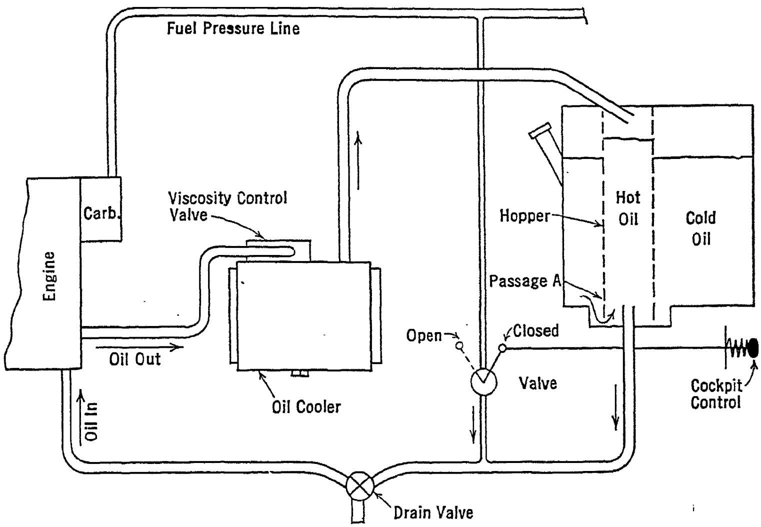


FIG. 124. Oil dilution, quick warm-up external oil system.

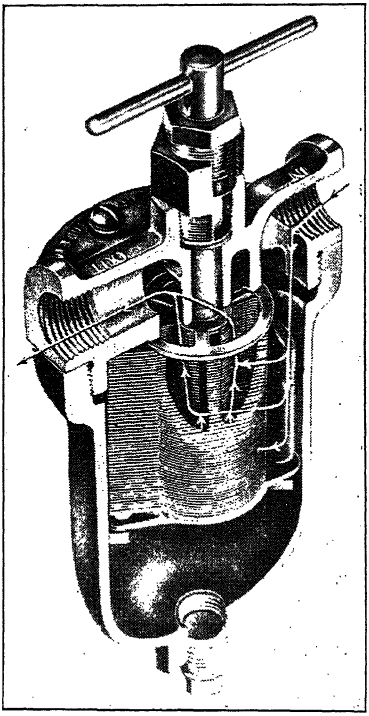
proper operating temperature. As the circulating supply of oil diminishes, it is replenished by the main supply in the tank passing into the circulating supply at passage *A*.

After the oil warms up dilution is not desirable. The heat of the engine distills off all traces of gasoline in 15 to 30 min. The majority of the effects of dilution are eliminated in the first 5 to 10 min of engine operation.

The use of a constant viscosity oil cooler is well illustrated in this system. A light oil, if maintained at the same temperature as a heavy oil, would be much thinner than the heavy oil. However, if the light oil is cooled sufficiently while the heavy oil remains hot, the light oil may attain a viscosity equal to the viscosity of the heavy oil. Since lubrication is a function of the viscosity, it is desirable to maintain a constant viscosity. As the gasoline-diluted oil passes to the cooler much more cooling will be required to maintain it at a certain viscosity than would be required to maintain undiluted oil at the same viscosity.

As the gasoline boils off and the dilution diminishes, the amount of cooling necessary to maintain the same viscosity diminishes. The constant viscosity valve determines the amount of cooling necessary to maintain the viscosity constant, and directs the oil accordingly through the cooler core or jacket.

Oil Cleaners. Oil filters are for removing the solid contaminants from the oil. A filter which would remove the smallest solid contaminants from an oil would either be prohibitive in size or require excessively high pressures to force the oil through. A filter which would remove liquid contaminants would have to have some substance in the filter which would remove by absorption the liquid contaminant and still not absorb the oil to any great extent. As far as is known, no practical filter of this type has been developed for aircraft engine use. The ability of a filter to neutralize is also limited because any substance added to a filter to neutralize acid often results in the formation of compounds more objectionable than the acid itself.



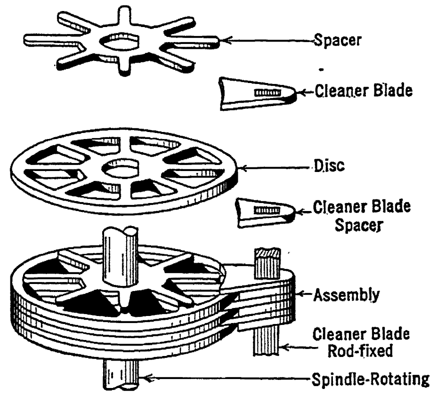
Courtesy Cuno Engineering Corporation

FIG. 125. Cut-away view of a Cuno Auto-Klean filter, showing oil flow path.

A filter very widely used in aircraft engine lubrication systems is illustrated in Fig. 125. This particular filter is for installation in the external system. Some engines make provisions for installing the filter in the internal system. The principle of the filter may be understood by viewing Figs. 125 and 126. The vertical dimensions of Fig. 126 have been exaggerated for clarity. A stack of discs and spacers is assembled on a shaft as illustrated. One end of the stack is closed and the other end is connected to the filter discharge. The stacking of the disc and alternate spacers virtually forms a fine mesh screen. Oil comes into the filter body surrounding the disc and must pass through the space between the discs before being discharged. When the assembly of discs and spacers is turned by means of the rotatable spindle,

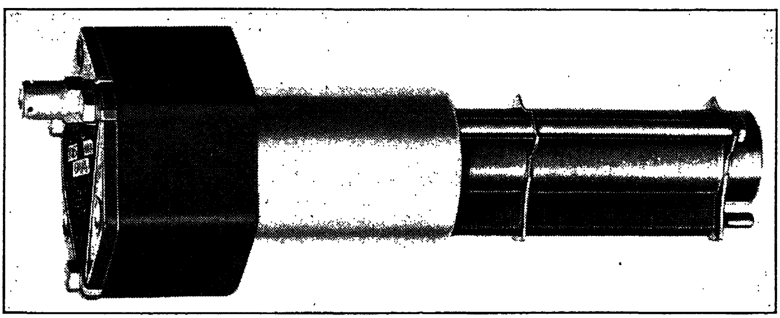
solids which have been lodged against the discs or between them are combed clear of the filter surface. The solids are not carried away from the filter assembly, but merely cleared from the disc and retained within the filter body on the input side of the screen.

Fig. 127 illustrates a filter similar to the one just described, but designed for installation in the internal lubrication system of an engine. The compartment of the engine into which the filter fits acts as the outer body. This particular filter has a hydraulic motor in the head which is operated by the engine oil pressure. The discharge side of the motor drains back to the inlet side of the engine oil pump. The hydraulic motor constantly rotates the discs while the engine is in operation, thereby keeping the discs clean. When the engine is not running the discs may be rotated manually by inserting a crank in the boss shown on the left of the head.



Courtesy Cuno Engineering Corporation

Fig. 126. Essential parts of the Cuno oil filter.



Courtesy Cuno Engineering Corporation

Fig. 127. Cuno self-cleaning oil filter, driven by engine oil pressure.

If the screen discs are allowed to become too dirty they will restrict the flow of oil and thus cause a drop in the oil pressure. The oil pressure gauge connection should always be connected to a point in the system past the filter. To avoid a drop in oil pressure while in

flight, on installations which do not have the continual cleaning filter, provision is sometimes made so that the filter discs may be rotated manually while in flight.

Wire gauze strainers are sometimes installed in both the internal and external lubrication systems. When installed in the external system they are generally close to the engine oil outlet. Here they receive the oil while it is still hot and thin, and they are also assured of positive pressure from the scavenging pump. A relief valve is usually provided to by-pass the oil should the screen become clogged. Screens of relatively fine mesh are commonly installed in engine sumps to strain the oil before it is picked up by the scavenging pump.

Oil Tanks. Oil tanks are usually constructed of aluminum or aluminum alloy sheet, although other materials such as stainless steel are sometimes used. The construction generally employs riveting and welding of the seams. The rivet heads of the aluminum tanks are welded over to prevent leakage. In the larger tanks internal baffles are employed for additional strength and to prevent surging of the oil within the tank. The tank must be provided with an expansion space which cannot be inadvertently filled with oil. It must also be provided with a vent and some means of measuring the oil in the tank. A coarse screen is usually provided at the outlet and a drain fitting is installed at the lowest point of the tank.

MAINTENANCE

Abuses during operation of the engine are not just hallucinations to be viewed academically, but are actual everyday occurrences. They are abuses which can and should be avoided.

Before starting an inverted or radial engine which has been idle one hour or more, the propeller should be pulled through at least three revolutions by hand, making sure, first, that the ignition switch is "Off." Oil may have drained into the lower cylinders and will cause considerable damage if not removed before starting. If an abnormal amount of effort is required to turn the propeller, the spark plugs must be removed and oil drained from the lower cylinders.

Upon starting an engine the oil pressure gauge should be watched closely. Oil pressure should begin to register within the first 15 sec. If it does not register within 30 sec, the engine should be shut off and the cause determined.

After an engine has been started, it should be allowed to idle for a few minutes to permit the oil to warm up, become thinner, and reach all moving parts. Engine manufacturers usually specify a maximum

warm-up speed which is, in most instances, close to and seldom over 1000 rpm.

If oil shutters are provided on the oil cooler, the circulating oil will warm up quicker with the shutters closed. Do not exceed the maximum warm-up speed until the oil temperature reaches the minimum operating limit. The engine should not be accelerated until the oil temperature is above the minimum operating temperature. Fast acceleration may put more load on the bearings than steady running at full power.

As previously mentioned, fast warm-up of the engine will result in quicker expansion of the pistons than of the cylinders and reduced clearances, insufficient for the proper lubrication, will result. Quick cooling of the engine may also result in insufficient clearances between the pistons and cylinder walls. This often occurs in flight. If an engine operating at a fairly high temperature is slowed down suddenly, the cylinders may cool faster than the pistons. This cooling of the cylinders reduces their diameter, and results in insufficient clearances between the two.

Constant stopping and starting of an engine, when the oil is not properly warmed up, condense relatively large amounts of water in the crankcase. A test was run on an internal combustion engine in a laboratory cold room at 0°F. The engine was started and brought up to normal operating temperature and then shut off. The operation was repeated, each time allowing the engine temperature to fall back to zero and then restarted. In as few as sixteen starts and stops, or complete heating and cooling cycles, enough water was formed in the crankcase from condensation to freeze the oil pump sufficiently solid to cause breaking of the oil pump shaft when the engine was restarted.

All oil must be drained from the system at regular intervals and replaced with new oil. The frequency at which oil should be drained will depend upon the conditions of operation and maintenance, the quality of the oil used, and the amount of oil carried in the system. It has been found that in installations which carry relatively large amounts of oil and are operated properly and, for the most part, at cruising horsepower, the oil changes may be made at intervals up to and above 100 flying hours. On installations where the engine is operated at or near its full horsepower for protracted periods of time, where the oil supply carried is relatively small, or where the engine is improperly operated or maintained, it has been found necessary to change the oil at intervals of 50 hr of flying time and less.

When the oil is changed, all drains in the engine sump, tank sump, cooler, and external lines should be opened. It is desirable to drain

while the oil is warm, as it will run faster and more will drain than when it is cold. The first oil to flow from each drain should be examined for excessive filth or metal particles. The failure of bearings and other parts may be detected by metal chips in the oil. Some engine sump plugs have a permanent magnet incorporated in them which will gather ferrous metal particles. This magnet should always be inspected. Nonferrous metals will not be gathered by the magnet, though, and can only be detected by examining the first oil out of the drain and the oil cleaners. All filters and strainers should be removed and cleaned.

After the drainage is complete, all drain plugs, filters, and strainers are replaced and all drain valves closed and safetied. The tank is refilled to the capacity marked on the filler cap. Care must be taken to prevent the entrance of any dirt, lint, or other foreign matter while refilling the tank.

At regular periods between oil changes, the engine sump should be drained and filters should be removed and cleaned. The Cuno oil filter should be removed and cleaned at periods of approximately 20 hr of operation. Conditions will vary this period. Before each flight the Cuno filter should be given several turns if it is not the automatic type. The oil pump relief valve should be removed and cleaned at regular intervals. A piece of carbon or other foreign matter under the relief valve seat will cause a decrease in the oil pressure.

Each time the aircraft is refueled, the oil supply should be checked and refilled, if necessary, to the proper level.

At regular engine checks, all external lines should be inspected for cracks, leaks, or chafing. All connections should be checked for tightness.

Oil tanks are, as a rule, installed in close proximity with the engine. Being so situated, they are subjected to rather severe vibration which causes cracking at various points and chafing at the points of support. Inspection of oil tanks should be made at regular intervals.

Cracks in aluminum tanks may be repaired by torch welding. Tanks must never be welded until they have been thoroughly cleaned of all traces of oil. If this is not done, serious accident may result from an explosion. Stainless steel, brass, and terne plate tanks may be repaired by soldering in place a proper patch plate, which is usually additionally secured by rivets. Hard aluminum alloy tanks cannot be repaired by welding or soldering. They must be repaired by either replacing a complete panel or riveting a proper patch plate in place, using an approved seam-caulking compound.

Oil tanks should be removed and thoroughly cleaned at periods

corresponding approximately to engine overhaul periods. A phenolic cleaner will remove sludge and carbon deposits. After this cleaner has been used, the tank should be partially filled with mineral spirits, kerosene, or clear gasoline and agitated for several minutes, making sure that the liquid reaches all parts of the tank. Live steam is often used for cleaning oil tanks. Cleaning with live steam or thoroughly washing with carbon tetrachloride should always be done to remove all traces of oil before welding is performed on a tank. After cleaning, the tank should be tested for leaks. All ports except one, to which an air valve and pressure gauge should be connected, should be closed off. The tank should then be put under a pressure of 3 to 5 lb per sq in. with an air pump. This pressure must not exceed 5 lb. Soapy water should be applied with a brush to the entire exterior surface of the tank, and any air bubbles which might be formed by air leakage should be observed. If no leakage occurs the exterior of the tank should be washed with clear water and, after the port plugs have been removed, the tank should be allowed to dry thoroughly, both externally and internally, before reinstalling.

Tanks which are to be placed in storage should be given a thorough cleaning and, after thoroughly drying, should be slushed internally with a light oil. All ports should be plugged to prevent entrance of foreign matter. If the tank does not have an external protective coating of lacquer or varnish it should be wiped completely with a rag wet with light oil.

Leaks in oil coolers may be repaired by using a first-grade tin-lead solder. Should core tubes require replacement, they may be removed by using two soldering irons having the ends shaped to fit the inside hexagonal dimension of the core tube. The heated irons should be inserted in the tubes at each end simultaneously and as the solder melts the tube may be pushed from the core. New tubes may be inserted after the space in the core is cleaned and the tubes may be resoldered with the hand iron.

Oil coolers should be thoroughly cleaned at periods corresponding approximately to engine overhaul periods. Sludge and carbon, when allowed to accumulate in the cooler core, restrict the flow of oil and diminish the heat transfer efficiency. Circulating mineral spirits (similar to kerosene) through the cooler will not remove hard deposits of carbon and sludge. A phenolic base cleaner is very good for cleaning coolers. The cooler should be filled with the cleaner and allowed to stand for several hours. The cleaner should then be circulated through the cooler for about one-half hour. A pumping unit will be necessary for this. After the cleaner has been circulated through the

cooler and drained from it, mineral spirits should be circulated through the cooler for about 15 min. After the mineral spirits have been circulated, the cooler should be thoroughly drained and blown out with dry, compressed air. The cooler should then be tested for leaks by applying an internal air pressure of 75 lb per sq in. and immersing in water.

When repairing leaks in radiators the solder often runs at points adjacent to the point of repair and results in leaks at these adjacent points. After repairing a leak, the radiator should always be tested as above to determine whether or not other leaks have been caused.

The phenolic cleaner mentioned above is a cold cleaner; that is, it does not have to be heated for use. It has no detrimental effects upon steel, aluminum alloy, magnesium, brass, or bronze and has proved very popular and satisfactory. The price of such a cleaner is relatively high, but the unit cost of cleaning parts with it is in line with or lower than that for other cleaners when the number of times it can be used and the man-hours required for cleaning are considered. Such cleaners can be purchased under several trade names such as Bendix Cleaner (Bendix Aviation Corp., South Bend, Indiana) and Kleenapart (Selig Co., Atlanta, Georgia).

Practically all water-mixed cleaning solutions contain either soap compounds or caustic soda. It is very difficult to remove all traces of these compounds from parts cleaned with them, and where compounds which contain soap are used oil foaming may result immediately after starting the engine. In the case of cleaners which contain caustic soda, the alkaline compounds combine with the oil, in the presence of acids which normally form in the oil, and form soap, which produces oil foaming. In this event, foaming may occur immediately or many hours after the engine is in operation.

Oil cooler spring-loaded relief valves, thermostat valves, and viscosity valves are nonadjustable. No attempt should be made to adjust them. In event of malfunctioning these valves should be replaced. Except for visually obvious failure of these valves, their improper functioning can only be determined by special test equipment.

Troubles Encountered in Lubrication System. The most common troubles encountered in the lubrication system, with their attendant remedies, are listed below:

1. *Low oil pressure, fluctuating pressure, or no pressure at all may result from one or more of the following:*

   a. Oil pressure pump not primed. Disconnect the oil suction line and fill the pump with oil. Turn engine over by hand until pump begins

pumping oil. Air may sometimes become trapped within the pump and relief valve mechanism. Removing and reinstalling the relief valve may eliminate the air lock.

b. Leak in oil suction line. Check suction line and all connections for air leaks.

c. Clogged oil screen. Remove and clean oil strainer.

d. Carbon, dirt, or other foreign matter on oil pump relief valve seat. Remove and clean relief valve.

e. Improper tension on relief valve spring. Adjust relief valve spring to obtain the oil pressure given on engine data plate. Adjustment should be made while the oil is hot. If adjusting screw has to be screwed all the way in to obtain correct pressure, trouble will probably also be found elsewhere.

f. Excessive bearing clearance. A bearing or bearings may be worn so that they bleed the oil from the system too quickly. In this event, overhaul will be necessary.

g. High oil temperature. With high temperature the viscosity is decreased excessively. Excessive decrease in viscosity thus gives excessive fluidity and the oil passes the bearings too freely, causing pressure to drop. Check operation of oil cooler and temperature of oil.

h. Congealed oil in suction line. Low temperature in very cold weather may congeal the oil in the suction line. Suction lines are often lagged for heat insulation during winter operation.

i. Foaming in oil supply tank. Foaming of the oil is a frequent cause of fluctuating oil pressure and loss of pressure. Air is normally present in the scavenged oil. The scavenged oil from the engine should be directed into the supply tank in such a manner as to produce a minimum of splashing. Any method to aid in separating the scavenged oil and air is desirable. Lack of proper venting will permit excessive foaming. Examine vent lines. Water in the oil will aggravate foaming. When foaming occurs, the oil should be removed from the system and replaced with fresh oil.

j. Oil pressure will vary with varying speeds and oil temperatures. Due allowance should be made for the pressure drop to be expected at increased temperatures.

k. Although the actual oil pressure of the engine may be correct, the pressure gauge in the cockpit may not be indicating the correct engine oil pressure. Heavy oil in the oil pressure gauge line during cold weather will congeal and prevent the gauge from indicating the correct pressure. To overcome this trouble, gauge lines should be filled with a light oil of about S.A.E. No. 10 viscosity. After a time a portion of the light oil may drain from the gauge line, allowing it to become partially filled with heavy oil or air or both. It will be necessary to refill the gauge line at intervals to keep it free of heavy oil.

2. *Excessive oil temperatures and high oil consumption may be caused by one or more of the following:*
   - *a.* Insufficient oil cooling.
   - *b.* Insufficient oil supply.
   - *c.* Low grade oil.
   - *d.* Suction pump failing to scavenge the oil properly from the crankcase.
   - *e.* Overheated bearings.
   - *f.* Contaminated oil.
   - *g.* Worn piston rings.
   - *h.* Piston rings incorrectly installed.
   - *i.* Restricted or clogged oil lines, strainers, or coolers.
   - *j.* Improper venting of oil system.
3. *Excessive accumulation of oil in the crankcase may be caused by one or more of the following:*
   - *a.* Lack of priming of the scavenging pump. Disconnect engine oil outlet line. Feed oil to the scavenging pump through the oil outlet connection while turning the engine backward until the pump is primed.
   - *b.* Restricted or clogged oil lines, strainers, or cooler on the oil outlet side.
   - *c.* High oil inlet temperature or pressure.

Precautions Necessary when Metal Is Found in Strainers. When metal particles are found in the sump or strainers, it is evidence of a failure somewhere in the engine. Of course, it will be necessary to disassemble the engine for overhaul. It will also be necessary to rid the external oil system of any metal particles which it may have gathered during the circulation. The complete external oil system should be dismantled. The tank should be cleaned out as previously described and particular attention should be given to the crevices and small clearances between the baffles and seams where small metal particles might become lodged. Steam or compressed air should be used to blow clear these potential traps. It may be necessary to cut extra hand-holes in the tank to get at all possible lodging points properly. As a final measure the tank should be rinsed thoroughly inside with mineral spirits, kerosene, or clear gasoline. All oil lines should be washed in mineral spirits, then swabbed out with clean rags and given another wash in clean mineral spirits. Drain valves and fittings should be cleaned the same as lines. Thermostatic and viscosity valves should be disassembled sufficiently to allow thorough cleaning.

Because of the construction of the oil cooler, it is considered practically impossible to remove all metal particles which might be lodged in it. Hence, it is recommended that oil coolers be discarded as unserviceable.

CHAPTER VII

IGNITION

Some method must be provided to ignite the charge in the cylinder at the correct instant. In the gasoline engine ignition is accomplished by an electric current jumping a gap to produce a spark. The gap is a small clearance between two electrodes well insulated from each other. These two electrodes are incorporated in one unit known as a spark plug.

A relatively high voltage is required to jump the gap. Two common methods for producing this voltage are the spark coil and the magneto. The spark coil is a form of transformer which converts a relatively low voltage into a high voltage. It is dependent upon some external source, such as a battery, for its primary current. The magneto is a current generator with a high output voltage.

The magneto has been almost universally adopted as the high voltage source for ignition purposes on aircraft engines. Perhaps the best reason for this is that it is a self-contained unit which is not dependent upon any external electrical source.

The majority of aircraft engines are equipped with dual ignition systems. Besides other advantages the dual system makes total failure less probable. In the dual ignition system two magnetos are used and there are two spark plugs in each cylinder. Some dual magnetos enclosed in one housing may appear to be a single magneto, but are in reality two complete magneto units except for common drive shaft and rotor.

The Aircraft Magneto. The operating principle of the aircraft magneto is based upon the properties of a common horseshoe magnet. A horseshoe or any permanent magnet has a magnetic field. This magnetic field may be represented by invisible lines commonly called *lines of flux.* The greater the number of lines of flux (flux density) the stronger the magnet. Every magnet has two poles, one called the south pole and the other the north pole. Within the magnet itself the lines of flux always flow from the south to the north pole. Each line of flux forms a closed circuit or loop. In the horseshoe magnet, Fig. 128, the lines of flux pass from the south pole through the magnet to the north pole and then through the intervening air return to the south pole. The presence of the lines of flux can be shown by placing

the horseshoe magnet under a piece of paper on which are spread iron filings. The iron filings will arrange themselves in definite positions along the invisible lines of flux which form the magnetic field as indicated in Fig. 128.

The air space between the poles is highly resistant to the concentration of the lines of flux. Consequently, they will spread over a considerable portion of the air space between the poles. The resistance which any material offers to the flow of lines of flux is known as reluctance. The reluctance of air is very high, whereas the reluctance of a laminated soft iron bar is very low. If a laminated soft iron bar is

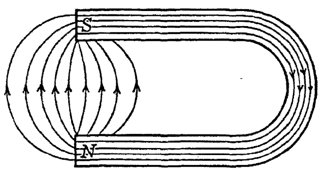


FIG. 128. Lines of flux in a permanent horseshoe magnet.

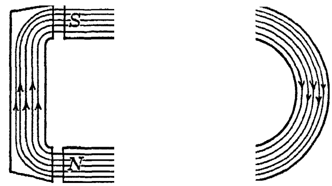


FIG. 129. Lines of flux passing through a soft iron bar.

placed near the poles of a horseshoe magnet as shown in Fig. 129, the lines of flux will pass through it because it offers a path of less reluctance than the surrounding air. The fact that lines of flux take the path of least resistance, and pass through the soft iron bar rather than the surrounding air, is taken advantage of in the magneto, as will be seen later.

When the lines of flux from the horseshoe magnet pass through the soft iron bar, the iron bar becomes an induced magnet. Its polarity is determined by the direction of flow of the lines of flux. From the flow in Fig. 129 it will be seen that the part of the iron bar which is over the north pole of the horseshoe magnet becomes a south pole and that part over the south pole of the horseshoe magnet becomes a north pole. Since unlike poles attract each other, the permanent magnet and induced iron bar magnet are attracted to each other. Should the horseshoe magnet be rotated 180 deg about its longitudinal axis while the bar is held stationary, the polarity of the bar and the direction of the lines of flux within it would be reversed.

If a wire is passed through a magnetic field an electric current will be generated or induced in the wire. The amount of current generated will be dependent upon the number of lines of flux cut by the wire per unit of time. Suppose several coils of wire are connected to a gal-

vanometer as shown in Fig. 130. (A galvanometer is an instrument for measuring the flow of an electric current.) The lines of flux of the horseshoe magnet, when in the position illustrated, pass through or *link* the turns of wire in the coil. When one line of flux passes through one turn of a coil, it is known as one *flux linkage*. If one line of flux passes through six turns of a coil, six flux linkages are produced. Accordingly, if six lines of flux pass through six turns of a coil, there are thirty-six flux linkages, and so on.

If the wire coils were brought from some remote position up to the position shown in Fig. 130, the number of lines of flux linking the coils would be constantly changing during the motion. In other words, there would be a change in flux linkages as the wire coils are moved.

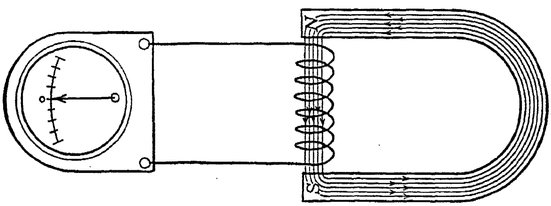


FIG. 130. Flux linking a coil of wire.

This change in flux linkage, produced by moving the wire coils, induces a current in the coils of wire which will be indicated by a deflection of the galvanometer needle. Should the wire coils be moved back to a remote position from the position shown in Fig. 130, another change in flux linkage would occur, inducing current in the coils in the opposite direction, which would be indicated by the galvanometer.

The amount of current induced is proportional to the rate of change of flux linkages. The flux linkages can be increased by adding more turns in the coil of wire or by using a stronger magnet which has more lines of flux. The rate involves an element of time and can be increased by passing the coils through the magnetic field with greater speed.

Current will be induced in the coils in the same proportion by holding the coils stationary and moving the magnet to produce the change in flux linkages. The Bendix-Scintilla aircraft magnetos employ a stationary coil and rotating magnet.

Current will not be produced in the coil of wire if the horseshoe magnet and coil of wire are both held stationary, even though the lines of flux link the coil turns. There must be a change in flux linkages to produce a current. This is important in the magneto because it illus-

trates the fact that the lines of flux must be given a magnetic path through the coil, and also that there must be a movement of either the coil or the magnet to produce a change in the flux linkages.

Whenever there is a current passing through a coil of wire, a magnetic field is set up which has the same properties as the horseshoe magnet.

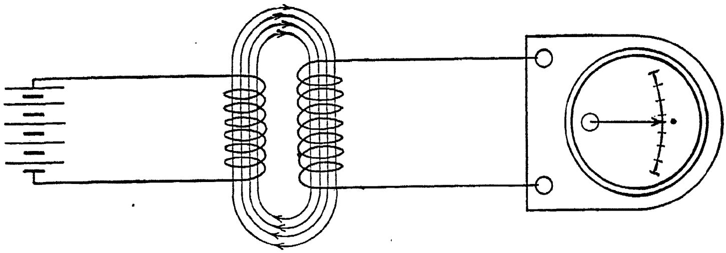
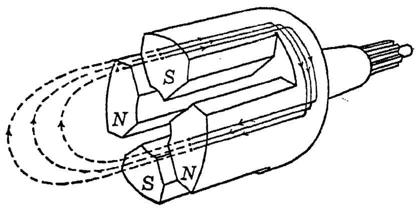


FIG. 131. Flux linking two coils of wire.

Fig. 131 shows the horseshoe magnet of Fig. 130 replaced by a coil of wire to which a battery is connected.

The current passing through the coil produces the magnetic field as shown. If, now, the coil connected to the galvanometer is moved away from the energized coil, a current will be induced in the coil connected to the galvanometer. Another way to produce a change in the flux linkages of the coil connected to the galvanometer would be to stop the flow of current to the energized coil. This would reduce the magnetic field to zero, and as the lines of flux disappeared a change of flux linkages would occur.



Courtesy Scintilla Magneto

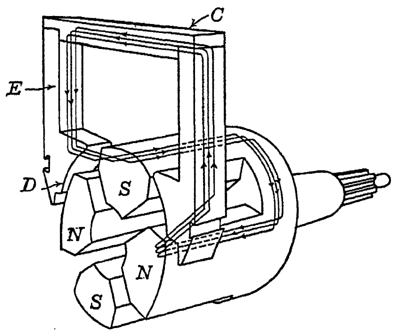
FIG. 132. Flux path in 4-pole magneto rotor.

The properties of the common horseshoe magnet are present in the rotating magnet of the magneto. Fig. 132 is a schematic illustration of a four-pole rotating magnet. The lines of flux in the rotating magnet, when not installed in the magneto, pass from its north poles through the air spaces to its south poles as indicated.

In Fig. 133, the pole shoes *D*, their extensions *E*, and the coil core *C*, which are made of soft laminated iron, form a magnetic path similar to that made by the laminated soft iron bar illustrated with the common horseshoe magnet in Fig. 129. This magnetic field produces a

concentration of flux in the core of the coil. The flux path shown in Fig. 133 is that which actually occurs in the magneto at the instant before the contact points open.

It will be noticed in Fig. 133 that the shoes are arranged so that they form a magnetic path for only one set of poles at a time. When one pole of the rotating magnets is centered between the two pole shoes there is no flow of lines of flux through the coil core. This is because the flux flows from one pole to the other through the pole shoe only. It might be said that the pole shoes "short-circuit" the flux and cause it to flow through themselves, rather than flow from one pole shoe through the coil core and then out the other pole shoe. The rotating magnets are said to be in a neutral position when one of the poles is centered and no flux passes through the coil core.



Courtesy Scintilla Magneto

FIG. 133. Flux path in a magneto rotor, pole shoes, and core.

As the rotating magnet is turned from its neutral position the lines of flux commence to pass through the coil core, increasing in magnitude up to a maximum when a north and south pole are each covered by a pole shoe. In the four-pole type of rotating magnet as shown in Fig. 133, the flow of flux through the coil core increases from a minimum to a maximum in 45-deg rotation of the magnets. As the rotating magnets move beyond 45 deg, the lines of flux in the coil core decrease in magnitude until at 90-deg rotation they are again at a minimum and the magnet is again in a neutral position. During the next 90 deg of rotation the flux flows in the opposite direction, but builds up to a maximum and then decreases to a minimum as in the previous 90 deg of rotation. The curve shown in Fig. 134 is a plot of the flux in the coil core at any position of the rotating magnet. It may be noted that the number of neutral positions, through which the rotating magnet will pass during one revolution, is equal to the number of pole pieces on the rotating magnet.

The primary winding of a magneto is made up of a comparatively few turns of heavy copper wire wound directly around the coil core. When the rotating magnet is turned, there will be a change in flux linkages, since the flux is constantly changing in the coil core. This change in flux linkages causes current to flow in the primary winding

while the contact points are closed, as shown by the primary current curve in Fig. 135. Up to a certain limit, any increase in speed of the rotating magnet induces more current in the primary winding because the rate of change in flux linkages is increased.

At every 90 deg or each quarter-turn of the rotating magnet (four-pole type), the flux reverses in direction through the coil core. This

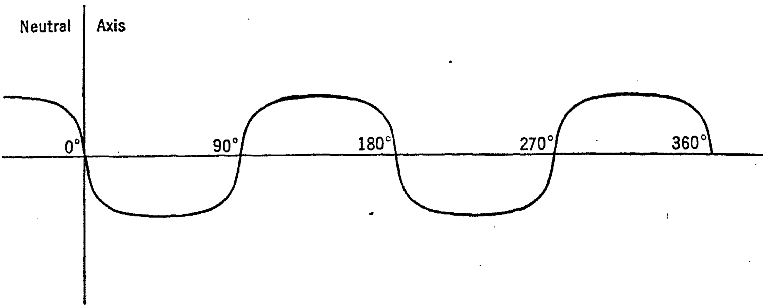


Fig. 134. Curve of the flux density in the coil core as a 4-pole rotor is rotated.

change of direction of flow of the flux results in a change of direction of flow of the current in the primary winding. A current which alternately changes its direction of flow is known as an alternating current. In Fig. 135 the change of direction is represented by the current curve being above the datum line when flowing in one direction and below the datum line when flowing in the opposite direction.

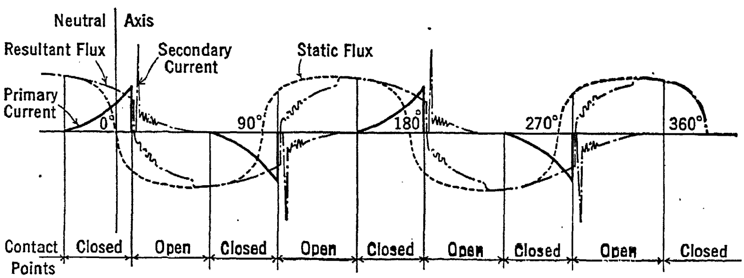


Fig. 135. Curves of the flux and current in a 4-pole magneto.

As we have previously learned, a current-carrying coil produces a magnetic field of its own. Accordingly, the current induced in the primary winding when the contact points are closed will set up a magnetic field of its own. The magnetic field produced by the current in the primary winding will oppose the change of flux linkages which

induced the current. This is shown graphically in Fig. 135. Without current flowing in the primary winding, the flux would be represented by the dotted curve labeled "static flux." However, the primary current induced when the contact points are closed prevents the flux from changing, as explained above, and actually results in storing up the flux as represented by the curve which is labeled "resultant flux."

The contact points, when opened, break the primary circuit. This interrupts the flow of the primary current, thereby removing the magnetic field set up by it. The flux which has been stored up is released in a very short interval of time. This results in a high rate of change of flux linkages which produces a high voltage in the secondary winding, consisting of several thousand turns of fine wire wound over the primary winding. The curve representing the current flowing in the secondary winding during the high voltage discharge is labeled "secondary current" in Fig. 135. The scale used for plotting the secondary current is, of course, different from the scale used to plot the primary current. If the secondary current were plotted to the same scale as the primary current it could not be shown completely in Fig. 135, because the primary current amounts to only several volts, whereas the magnitude of the secondary current is several thousand volts.

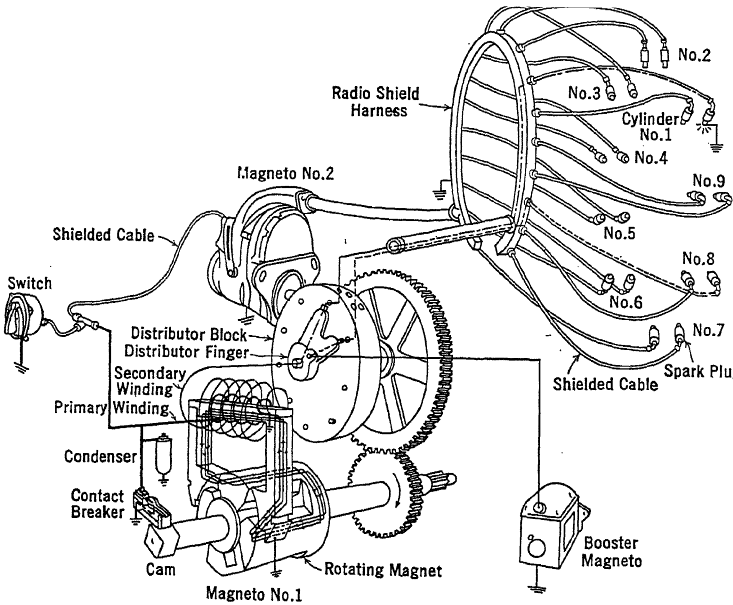
The contact points, which are in series with the primary winding as may be seen in Fig. 136, open when the rotating magnet reaches positions where the highest voltage will be produced in the secondary winding. The positions are predetermined by the designer and are specified by the number of degrees the rotating magnet is past its neutral position. This predetermined number of degrees is commonly known as the *E* gap.

Thus it may be said that the function of the primary winding and the contact points is to store up a magnetic field and then release it rapidly by the opening of the contact points for the production of the high voltage in the secondary winding.

When the high voltage in the secondary winding discharges, a spark jumps across the spark plug gap which ignites the fuel in the cylinder. Each spark actually consists of one peak discharge, after which a series of small oscillations occurs, as represented by the secondary current curve, until the voltage becomes too low to maintain the discharge. During the time it takes for the spark to discharge completely, current is flowing in the secondary winding.

After the contact points open only an infinitesimal period of time is required before the high voltage is produced in the secondary winding. During this time, the greatest rate of change in flux linkages occurs, as is shown on the resultant flux curve.

As soon as current flows in the secondary winding, a magnetic field similar to that made by the primary current is set up which opposes the change in flux which produced it. Therefore, the flux will no longer follow the nearly vertical part of the resultant flux curve but will taper off gradually to the static flux curve as long as the spark is still discharging.



Courtesy Scintilla Magneto

FIG. 136. Complete magneto ignition system with one magneto in skeleton, showing flux and current paths.

Besides producing a high voltage in the secondary winding, the flux which has been released will also cause a current to flow in the primary winding during the time the contact points are separating. This current would ordinarily arc across the contact points and result in excessive burning and pitting. To prevent this, a condenser (Fig. 136) is connected across the contact points to absorb the current which is commonly known as the self-inductance of the primary winding.

A complete aircraft ignition system, consisting of two magnetos, radio shielded harness, spark plugs, switch, and a booster magneto is illustrated in Fig. 136. One magneto is shown completely assembled and the other is in skeleton form showing electrical and magnetic circuits.

One end of the primary winding is grounded to the magneto. A

ground may be used instead of a wire in an electrical circuit. Every connection which is made to a common ground may be considered as connected to one common terminal. The other end of the primary coil is connected to the insulated contact point. The other contact point is grounded. The condenser is connected across the contact points.

A switch which is grounded on one side has the other side connected to the insulated contact point. When the switch is closed an electrical path is provided which grounds both ends of the primary coil. Therefore, when the contact points open, the primary current is not interrupted. This prevents the production of high voltage in the secondary winding. From the above it will be seen that when the ignition switch is turned "On" for operation of the magneto the switch is actually opened.

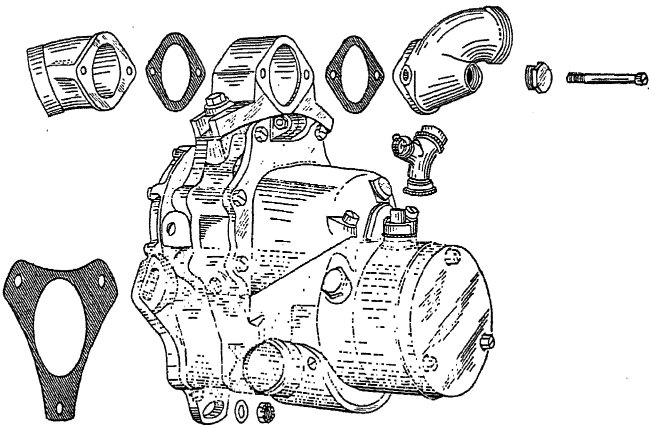


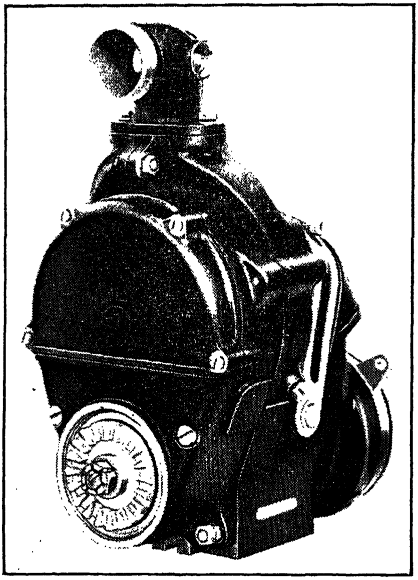
FIG. 137. Flange-mounted magneto complete with mounting gasket and wire-shielding connectors.

One end of the secondary winding is also grounded to the magneto. The other terminates at the high tension insert on the coil. The high tension current produced in the secondary winding is then conducted to the central insert of the distributor finger by means of a carbon brush. From here, it is conducted to the high tension segment of the distributor finger and across a small air gap to the electrodes of the distributor block. High tension cables connected to the distributor block then carry it to the spark plugs, where the discharge occurs.

The distributor finger is secured to the large distributor gear which is driven by a smaller gear located on the driveshaft of the rotating magnet. The ratio between these two gears is such that the distributor

finger is always driven at one-half engine crankshaft speed. This ratio of the gears insures proper distribution of the high tension current to the spark plugs in accordance with the firing order of the particular engine.

The rate at which sparks are required for each complete revolution of a 4-stroke cycle engine is equal to one-half the number of cylinders the engine has, since each cylinder requires a spark every second revolution. The number of sparks produced by each revolution of the rotating magnet is equal to the number of its poles. Therefore, the ratio of the speed at which the rotating magnet is driven to the engine crankshaft speed is always half the number of cylinders on the engine divided by the number of poles on the rotating magnet.



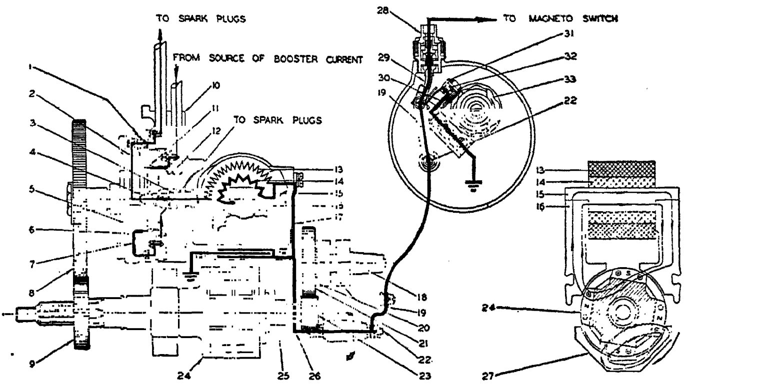
Courtesy Scintilla Magneto

FIG. 138. Base-mounted magneto. (Notice the serrated drive coupling. The engine drive has either one more or one less serration to allow adjustment by rotation of the intermediate serrated rubber coupling.)

The contact point breaker cam is provided with lobes which open the breaker points when the rotation of the rotating magnet is such as to deliver the maximum voltage output. The breaker cam of a four-pole rotating magnet, if mounted on the rotating magnet shaft, would have four lobes. Owing to the geometry of the master and articulated connecting rods of a radial engine, the top dead center position of each piston is not exactly proportional to the same number of degrees of crankshaft rotation. Hence, if it is desired to have ignition occur in each cylinder while the piston is the same distance from top dead center, it will be necessary to make a compensation at the breaker cam, since the cam is driven in direct relation to crankshaft revolutions. To make such a compensation it is necessary to use a breaker cam which has the same number of lobes as there are cylinders. The cam is geared to turn at one-half crankshaft speed. The cam lobes are ground at unequal intervals to compensate for the slight top dead center variations of each piston of the radial type of

engine. The unequal intervals between the cam lobes result in having the contact points open at the exact predetermined full advance firing position of the pistons. On the magneto, however, the E gap varies slightly for each contact point opening. As previously mentioned, the E gap is the number of degrees the rotating magnet has passed its neutral position when the contact points begin to open.

Sparks are not produced by the magneto until the rotating magnet is turned at or above a certain number of revolutions per minute, at



SCHEMATIC DIAGRAM OF ELECTRIC AND MAGNETIC CIRCUITS

DISTRIBUTOR BLOCK ELECTRODE
DIST'R FINGER HIGH TENSION SEGMENT
HIGH TENSION CONTACT BUTTON
CARBON BRUSH
DISTRIBUTOR GEAR AXLE
DISTRIBUTOR FINGER
BOOSTER SEGMENT
DISTRIBUTOR GEAR - LARGE
DISTRIBUTOR GEAR - SMALL
DISTRIBUTOR BLOCK
BOOSTER COLLECTOR RING

12 INSERT - BOOSTER CURRENT
13 SECONDARY WINDING
14 PRIMARY WINDING
15 COIL CORE
16 POLE SHOE EXTENSIONS
17 PRIMARY CONNECTOR - COIL TO CONDENSER
18 CAM SHAFT
19 CONNECTOR - TO CONTACT ASSEMBLY
20 CAM SHAFT BEARINGS
21 CAM GEAR - LARGE
22 INSULATED POST

23 CAM GEAR - SMALL
24 ROTATING MAGNET
25 PRIMARY CONDENSER
26 PRIMARY CONNECTOR - CONDENSER TO INSULATED POST
27 KEEPER - MAGNET POLES
28 GROUND TERMINAL OUTLET
29 CONNECTOR - CONTACT ASS'Y TO GROUND TERMINAL
30 SUPPORT - CONTACT BREAKER
31 SPRING - CONTACT BREAKER - MAIN
32 CAM FOLLOWER
33 BREAKER CAM

Courtesy Scintilla Magneto

FIG. 139. Schematic diagram of magneto electric and magnetic circuit.

which speed the rate of change in flux linkages is sufficiently high to induce the required primary current and the resultant high tension output. This speed varies for different types of magnetos but the average is 100 rpm. This is known as the *coming-in* speed of the magneto.

When conditions, such as are encountered in starting, make it impossible to rotate the engine crankshaft fast enough to produce the coming-in speed of the magneto, a source of external high tension current is provided for starting purposes. This may be either in the form of a booster magneto or a high tension coil to which primary current

is supplied by means of a battery. The high tension current from the booster system is conducted to the booster electrode on the distributor finger and across the air gap to the distributor block electrodes and thence through cables to the spark plugs.

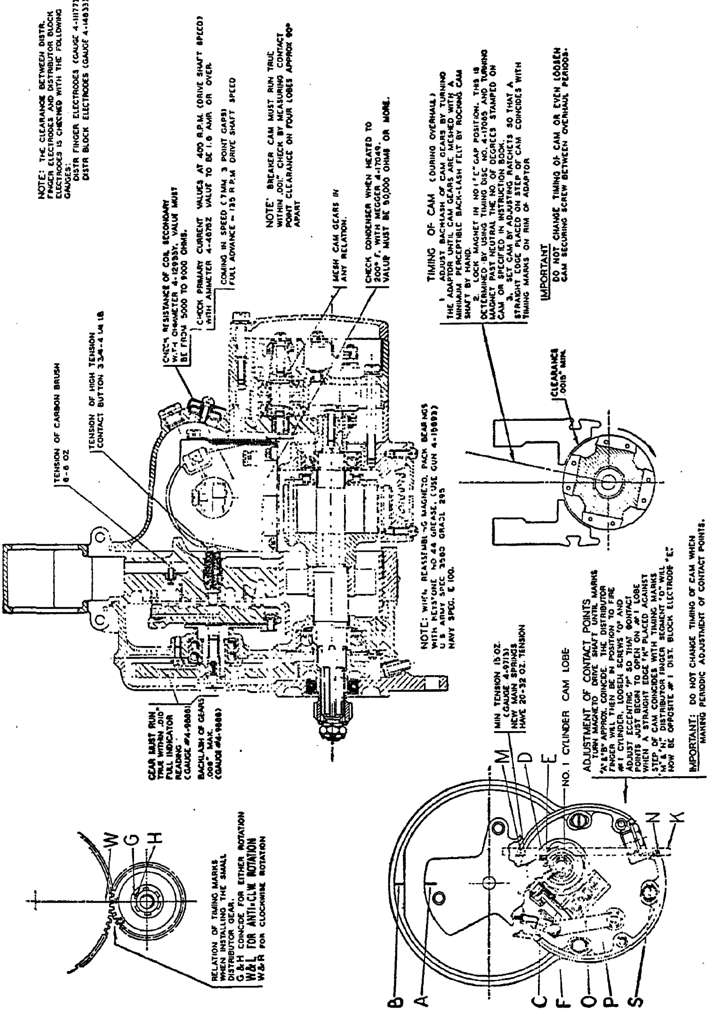
The booster electrode always trails the high tension segment of the distributor finger to give a retarded spark for starting the engine which prevents backfiring. When the distributor finger high tension segment is in position to fire No. 1 cylinder, the booster electrode is in position to fire the preceding cylinder of the firing order of the engine.

Ignition Harness. The collection of high tension wires which conduct the high tension current from the magneto distributor blocks to the spark plugs is commonly called the ignition harness. Since a magneto is a form of high frequency generator, radiations emanating from it during operation will result in interference with radio reception if the complete ignition system is not shielded. This shielding, which may be considered a metallic "can" enclosing the complete system, is grounded to the engine. It picks up the undesirable radiations or uncontrolled wave lengths produced by the magneto and carries them directly to the ground. Thus the undesirable radiations are prevented from reaching the airplane's radio aerial and causing interference with reception.

Several methods are used for shielding the ignition harness. One method is to conduct all wires from the distributor block through a partially rigid metallic manifold to a point from which the wires are conducted singly to the spark plug through a metallic tube or braid. Another method is to cover each wire individually with a metallic braid from the distributor block to the spark plug. The latter method has the disadvantage of having more condenser effect than the former; this reduces the effective voltage at the spark plug.

The core of high tension wire is made of several strands of small wire. This makes the cable more flexible than if it were composed of only one large strand. Some cables are made with copper wire strands and others use stainless steel. Cables of equal tensile strength will have fewer strands in the stainless steel cable than in the copper cable. This is a factor for consideration, because the condenser effect is decreased by a reduction in the size of the conductor.

The insulation covering is made of rubber, synthetic rubber, or a combination of both. Some cables have a rubber inner insulation and a synthetic rubber outer cover and others are completely covered with synthetic rubber. The advantage of the synthetic covering is that it is much more resistant than natural rubber to the deteriorating effects of weather, petroleum products, and other destructive agencies. An

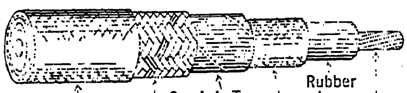


Courtesy Scintilla Magneto

FIG. 140. Service chart of Bendix-Scintilla Type SF9L-4 Magneto.

outer cover of lacquer-coated fabric is usually applied as an added protection against deterioration of the insulation. Great care should be exercised to prevent breaking or rupturing this coating.

A cable which has recently been put on the market has a fabric braid inserted in the insulation covering. The purpose of this braid is to reinforce the insulation cover so that a high pressure on the inside of the cover will not blow it out. There is naturally some air between the wire strands of the core. Sometimes even water finds its way in among the strands. Being in close proximity with the engine, the ignition harness naturally rises in temperature while the engine is running. Should air or moisture between the strands of the ignition wire be trapped so that escape is not possible, then the pressure rise within the wire core tends to blow the insulating cover outward. A sufficiently high pressure will blow a hole in the insulating cover. Should this occur a circuit may be formed to the ground.



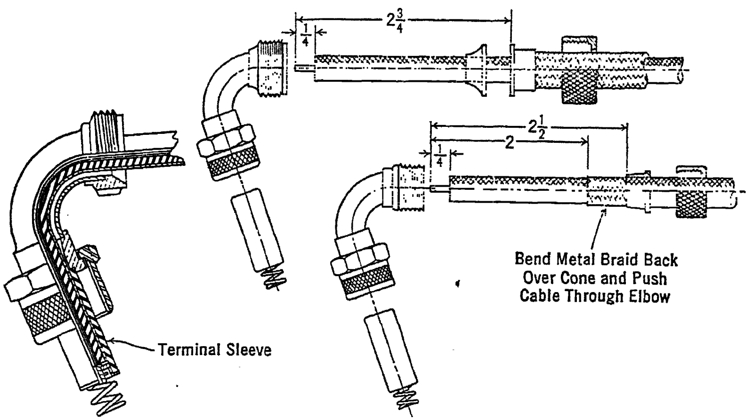
Courtesy Packard Electric

FIG. 141. Shielded high tension ignition cable.

When a high voltage current passes through a wire an electrical phenomenon known as *corona action* is set up. One of the results of corona action is a change of part of the oxygen (O_2) of the atmosphere into ozone (O_3). Ozone has a very deteriorating effect on both rubber and synthetic rubber. The continued effect of ozone will eventually deteriorate the insulation cover to such an extent that its dielectric (insulation) strength breaks down. It was once believed that the corona action only affected the portion of the insulation exposed to the outer air. Recent investigation shows that the inner surface of the insulating cover may also be affected. Perhaps an ignition wire will be developed that will eliminate the air spaces between the strands, thereby eliminating two objectionable conditions.

Moisture is very objectionable when encountered in an ignition harness. A continued soaking in water of the wire insulation will cause the dielectric strength of the insulation to be reduced. Several methods have been resorted to for the elimination of moisture from the inside of the ignition harness shielding. Some of these methods also eliminate the air surrounding the insulation cover which is a desirable feature. One method of eliminating both air and moisture is to make the shielding cover as airtight as possible and then fill all space not occupied by the wires with some plastic, oil, or other material which has a fairly good dielectric strength. The problem encountered in this

method, though, is that it is very difficult to make the shielding airtight. With the shielding not airtight the filler will leak out, if it is liquid. A solid rigid filler cannot be used throughout the harness as certain portions, such as the leads to the spark plugs, must be flexible. One ignition harness now under test, which uses as a filler a thick, grease-like material with a good dielectric strength, is meeting with fairly good success. One of the requirements of the filler is that it must not vaporize at the ignition harness temperatures or else it will force itself out of the shielding.



Courtesy The B. G. Corporation

Fig. 142. Ignition harness shielding elbow assemblies.

Another method now in use to eliminate moisture from the ignition harness is to pump dry air into it continually. The air is dried by conducting it through a dehydrating agent before pumping it to an inlet in the harness shielding. The air leakage of the shielding, which is reduced as much as possible, allows a continual flow of dry air to fill the inside of the shielding. Any moisture which might already be in the harness would be vaporized and eventually carried out.

The most vulnerable points on the ignition harness are at the terminals where the ignition wires connect to the spark plugs. These terminals seem to be a never-ending source of trouble.

The vast majority of spark plugs used with shielded harnesses are shielded plugs. If an unshielded plug is used and radio interference is to be prevented, then a shield must be installed completely around the unshielded part of the plug. Fig. 142 shows the common methods of connecting an ignition wire to the shielded spark plug. The wire

first passes through an elbow and then into a terminal sleeve. The only reason for an elbow rather than a straight fitting is that in most installations the relative position of the spark plug and the path of the ignition wire leading to the plug is such that the path of the wire is approximately 90 deg to the axis of the plug. The wire shielding terminates at the end of the elbow where the wire enters, the elbow being the shield from there to the spark plug. The terminal sleeve into which the wire passes is usually made of a plastic or other solid insulating compound, although some have been made of synthetic rubber. On the end of the sleeve is a small coil spring which insures good contact with the spark plug electrode. The wire strands are bent over at the end of the sleeve and make contact with the coil spring. The terminal is inserted into the shielding shell of the spark plug and the elbow nut is screwed up to hold it in place.

The portion of the ignition wire which goes into the spark plug gets hotter than the wire at any other point in the system. This excessive heat, of course, causes that portion of the wire in the spark plug to deteriorate faster than the remainder. To augment the deteriorating effect of the heat there are moisture and corona action to contend with.

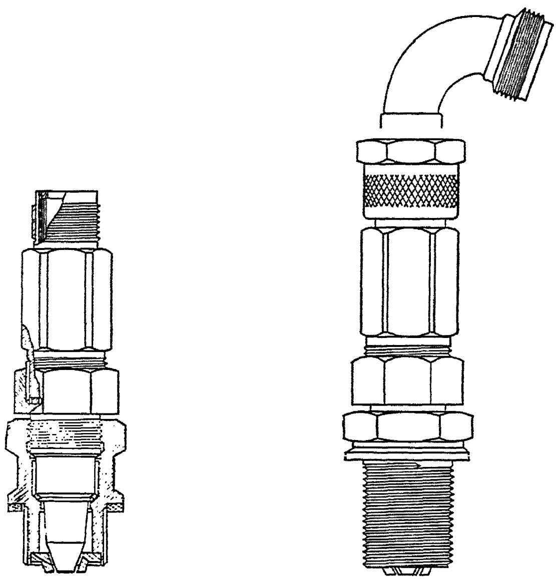
When the plug heats up the temperature rise causes what air there is in the plug to expand. If there were no other way for the air to escape it would travel through the spaces between the wire strands of the ignition cable and out at the magneto terminals. If the magneto terminals were airtight, as they often are, the expanding air would then have a tendency to blow out the insulating cover. However, there is usually some place for the air to escape other than through the wire strands and it is usually at the elbow nut which attaches the wire shielding. When the engine is shut off the air remaining in the plug cools and contracts, drawing air and sometimes water into the shell of the plug. There is a certain amount of moisture in the air drawn into the shell, and if the plug cools sufficiently water will be condensed from the air. This water aids in decreasing the dielectric strength and deteriorating the insulation.

The corona action forms ozone from the oxygen of the air within the spark plug shell. The ozone remains in intimate contact with the insulation and does its part in deterioration. The corona action also converts some of the nitrogen from the air into NO. This mixed with water (H_2O) forms H_2NO_3 (nitric acid). The nitric acid has a deteriorating effect upon the insulation as well as on those metal parts with which it comes in contact. Terminal sleeve contact springs made of stainless steel are least affected by the nitric acid.

One method of solving the problems just mentioned has been to fill

all air spaces within the plug shell with the grease-like compound of good dielectric strength, which was mentioned previously as a harness filler. This has met with fairly good success, but there is a tendency for the compound to dry out and cake at the higher temperatures within the spark plug shell.

The washers placed around the wire at the end of the elbow to which the flexible shielding attaches aid in keeping moisture out of the plug while the engine is running, but they cannot be depended upon to keep



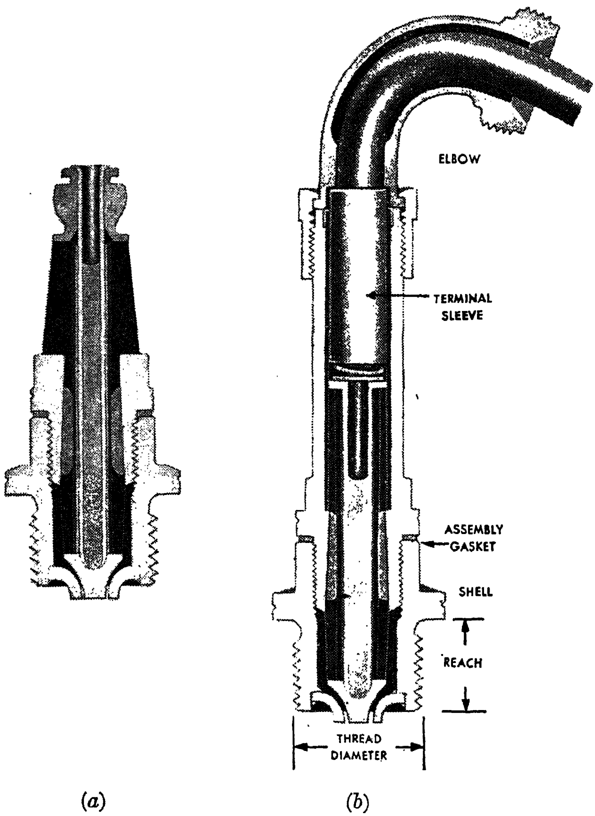
Courtesy Aero Spark Plug Company

FIG. 143. Cross-sectional and assembled views of Aero shielded spark plugs.

moisture out as the plugs cool off. Making the washer smaller in inside diameter to make it tighter around the wire only results in a *necking* of the wire which gives the wire insulation a permanent set with a smaller diameter.

Spark Plugs. The spark plug provides the gap within the cylinder across which the electric current arcs to make a spark to ignite the fuel-air mixture. The two electrodes which form the gap must be well insulated from each other so that the electric current will not complete its circuit before it arrives at the gap. The material used for insulation is usually a high grade of mica. The mica within the shell of shielded plugs is in the form of a sheet rolled into a tube. The insulation around the center electrode in both shielded and unshielded plugs consists of

stacks of thin mica washers placed around the electrode after wrapping it with sheet mica. The method of assembly and the shape of the electrodes vary with different manufacturers. In general it may be said that the electrodes are made as large as possible at the gap. This provides more sparking area and insures less rapid increase in the gap distance than where sparking is confined to a small area.

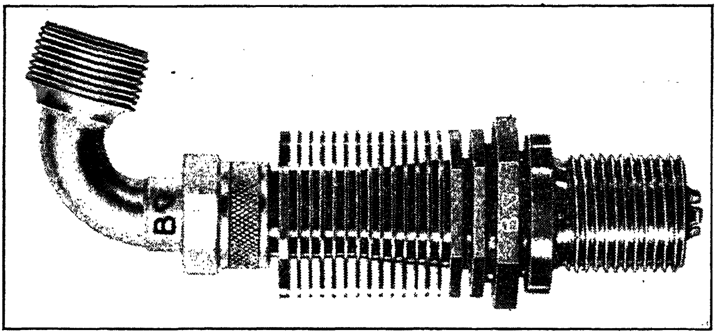


Courtesy The B. G. Corporation

FIG. 144. Cross-sectional views of (*a*) unshielded and (*b*) shielded spark plugs.

The temperatures at the spark plug are higher than at any other point in the cylinder. It is, therefore, necessary for the spark plug continually to dissipate a relatively large amount of heat. To do this good heat conductors, such as copper, are often incorporated in the construction of the plugs. Some plugs are finned, like cylinders, to aid in the dissipation of heat.

The brake mean effective pressure of the cylinder is a fair criterion of the heat which the plug must dissipate. A plug which conducts too much heat away is known as a *cold* plug and one which does not conduct enough heat away as a *hot* plug. Fouling of the plug will be experienced if too cold a plug is used. A plug that is too hot will cause detonation and preignition. The proper spark plug is one which will operate at a temperature high enough to keep carbon removed and low enough to prevent preignition. The engine manufacturer should be consulted regarding the proper spark plug to be used with a particular engine.



Courtesy The B. G. Corporation

FIG. 145. A finned shielded spark plug.

Magneto Installation and Timing. In considering the timing of magnetos there are two timing operations. First, the magneto must be timed so that the breaker contact points open at the correct instant to give maximum voltage. Second, the magneto must be timed to the engine so that the breaker contact points open and ignition occurs at the correct position of the pistons or, as it is usually designated, the correct crank angle.

The angular position of the rotor at which the highest voltage will be produced is usually specified as so many degrees past the neutral position of the magnets. This angular distance is called the *E* gap. Scribe marks and symbols are usually placed on the gears or other rotating parts of the magneto to indicate the correct position of the rotor at which breaker points should open.

A variable spark magneto is one which can have the spark time either advanced or retarded by rotating the breaker contact point assembly about the breaker cam. A variable spark magneto is most generally adjusted for best spark with the breaker points in the full

advance position. Thus, when the spark is retarded the voltage naturally decreases.

There are two methods of mounting a magneto on an engine. One is to mount the magneto with a flange which has elongated holes so that the magneto can be rotated about its own shaft. Such a magneto is shown in Fig. 137. Another method is to mount the magneto on a rigid base which does not permit its rotation.

Assuming that the magneto has been timed so that the breaker points open at the point for best voltage, the procedure for timing a flange-mounted magneto to the engine is as follows:

1. Turning the engine crankshaft in its normal direction of rotation, set the piston of No. 1 cylinder at its full advance firing position. The firing position must be obtained from the engine data. It is designated as so many degrees before T.D.C. (top dead center) on the compression stroke. The method of setting a piston at a designated number of degrees before or after T.D.C. is discussed under *timing* on page 364.

2. If the magneto is the variable-spark type, the breaker assembly is rotated to the full advance position.

3. Rotate the magneto drive shaft until the distributor finger is opposite the distributor block electrode for No. 1 cylinder. At this position the breaker points should be just beginning to open.

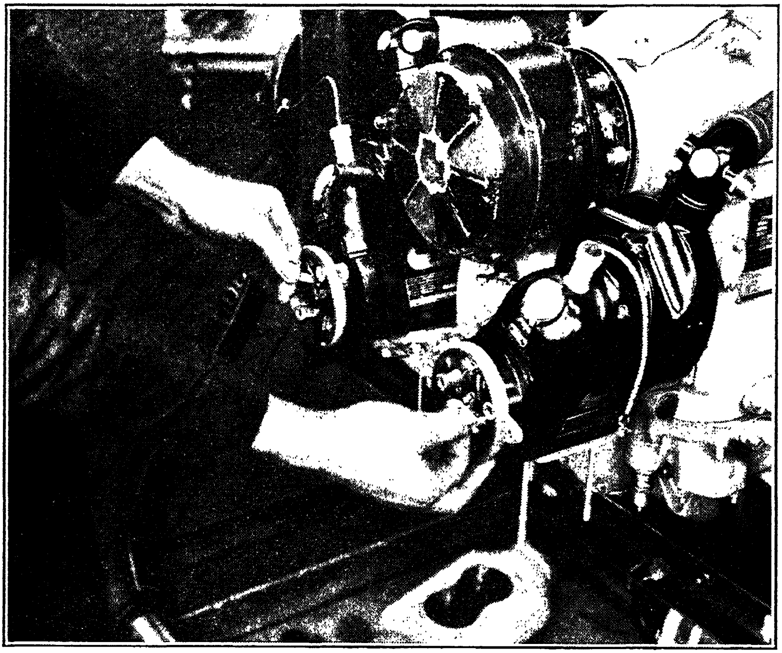
4. Make sure that the mounting faces are clean and smooth. Coat the drive spline of the magneto with a heavy vaseline to prevent rust. Install the magneto on the engine, but do not draw the bolts up tight. Rotate the magneto as much as the elongated mounting holes will permit. During this rotation the breaker points should open and close. If they do not the magneto will have to be removed, the drive rotated one spline, and the magneto reinstalled.

5. Rotate the magneto in a direction opposite the normal shaft rotation until the breaker points are just opening. To determine the time of opening a piece of thin cellophane or a 0.0015-in. feeler gauge may be used. Insert the cellophane between the breaker points. While the cellophane is pulled on slightly, it will begin to slip as the points are just beginning to open. When the breaker points are just opening, lock the magneto in place by tightening the mounting bolts. Be sure that pieces of cellophane are not left between the breaker points after timing is complete.

Each of the magnetos of a dual ignition system is timed as above. After the timing of each is complete they should be checked for synchronization. The engine crankshaft should be rotated backwards

about 90 deg. Then, as the crankshaft is being rotated in the normal direction of rotation, the opening of the breaker points should be checked, the cellophane being used as before. Breaker points on both magnetos should open simultaneously.

On some engines the ignition time is staggered. One magneto fires later than the other. On engines of this type the magnetos must be timed separately with the No. 1 cylinder set to the specified advance for each particular magneto.



Courtesy Pratt and Whitney Aircraft

FIG. 146. Synchronizing magnetos using thin feeler stock to detect opening of the contact breaker points.

Besides using the cellophane or feeler gauge as just described, an electrical circuit connected in series with the breaker points may be used to check the time of opening of the points. A light, buzzer, or other indicating instrument in the circuit will indicate when the points are open or closed. This method is not recommended, though, unless it is certain that a current across the contact points will not energize the primary coil and demagnetize the permanent magnets through the magnetic field which is set up.

For timing a base-mounted magneto to the engine the same procedure as for the flange-mounted magneto is used throughout, except that to adjust the time of opening of the points another method must be used. The final timing adjustment is accomplished by adjustment at the drive coupling between the engine and the magneto. The adjustment, if made by rotating the breaker point assembly or cam, would result in a lower output voltage.

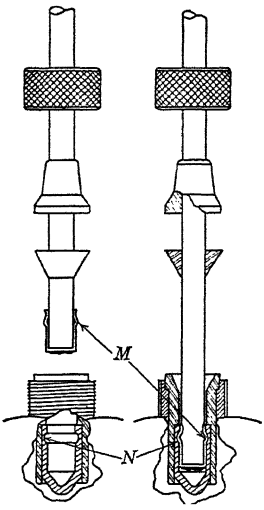
Several arrangements have been devised for making adjustments at the magneto drive coupling. One in general use is a round rubber drive coupling with notches on both faces, to mate with the engine drive on one face and the magneto drive on the other face. Because the coupling has, say, 19 notches on the face that meshes with the engine drive and 20 notches on the face that meshes with the magneto drive, adjustment can be made by rotating the coupling with relation to the two drives. A very fine adjustment can be made by rotating the coupling only a few notches. It is necessary to slip the magneto away sufficiently to allow turning of the rubber drive coupling. The direction in which the drive coupling will have to be rotated to advance or retard the opening of the breaker points will depend upon the normal rotational direction of the magneto and upon whether the engine drive or magneto drive has the greater number of notches. The coupling should be rotated in both directions and an inspection made to determine whether the time of point opening is being advanced or retarded. The adjustment can then be made.

There seems to be a prevalent erroneous impression that, as long as magneto breaker points have a specified clearance between them when full open, they are correctly adjusted. The clearance between the points is not a criterion of proper timing. Proper timing can only be definitely determined by actual time of opening of the breaker points. Of course, the points should have a proper clearance when they are in the full open position, which is in the neighborhood of 0.010 in. This clearance should be checked before magneto installation and at periods between overhauls. Too small a clearance may cause excessive arcing or incomplete opening of the circuit and too large a clearance may prevent the points from following the motion of the cam.

The numbers on the distributor block denote the magneto sparking order and do not represent the cylinder number to which the wire from that terminal should be connected. The wire from distributor block terminal marked "1" should be connected to No. 1 cylinder, but the wire from terminal marked "2" must be connected to the second

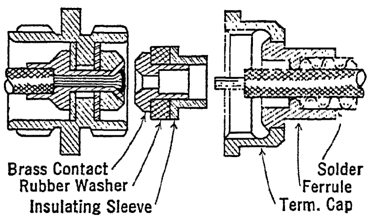
cylinder to fire and not the No. 2 cylinder. The firing order of the cylinders for the particular engine must be ascertained. The firing order of a single-row radial engine will be 1, 3, 5, 7, 9, etc., 2, 4, 6, 8, etc.

Cable-piercing screws are usually provided in the distributor blocks. Before installing the cables these screws should be removed to avoid any possibility of the high tension cables not being fully seated in the base of the cable holes. After the cables have been properly secured in their proper positions, hot paraffin is sometimes poured into the cable holes of the distributor block to fill up the space around the cable and prevent the entrance of moisture. If paraffin is not used it is recommended that parts of the cable which go into the distributor block holes be treated with talcum powder or mica dust to prevent their fusing to the walls of the distributor block cable holes. A high tension cable terminal, used on the Bendix-Scintilla Series SF4R and SF4L magnetos, which does not utilize the cable-piercing screws is shown in Fig. 147. This type of terminal, which requires more space than the cable-piercing screw arrangement, can be used on these series magnetos as there are few cable terminals.



Courtesy Scintilla Magneto

FIG. 147. One type of magneto high tension cable terminal.



Courtesy Scintilla Magneto

FIG. 148. One type of magneto ground cable terminal.

The cable from the booster source is connected to the terminal provided for it and secured by the means provided. In a dual ignition system the booster source is connected to only one of the magnetos. Connect the cable from the cockpit ignition switch to the magneto ground terminal. The method of connecting the ground terminal to some types of Bendix-Scintilla magnetos is shown in Fig. 148.

Before installing the magneto covers and shielding, all of the high tension wires should be checked to ascertain that they are connected to the proper cylinder. This may be done by an electrical circuit containing a battery in series with a light, buzzer, or other instrument which will indicate a flow of current. One end of the circuit is touched against the distributor block electrode and the other end against the spark plug end of the cable for the proper cylinder. If the ignition cable is correctly connected the electric circuit will be closed, as the buzzer signal, lamp light, or other instrument will show. Each ignition cable should be *rung out* in this method.

Before connecting the terminal sleeves at the spark plugs, one must make sure the sleeves are wiped dry and are not scratched or cracked. Care should always be exercised to prevent damage to the terminal sleeves while disconnecting or connecting them at the spark plug. The sleeves should not be touched with the fingers after they have been wiped dry as oil, dirt, moisture, salt, and other things which may be on the fingers will cause flashover and eventual failure of the sleeve.

Spark Plug Installation. The installation of spark plugs is sometimes comparatively difficult because of the restricted space around the plug hole. One should always make certain that the threads start straight before tightening down on the plug or otherwise threads, probably those of the cylinder bushings, will be stripped. A socket wrench of proper depth should be used for installing and removing plugs. A hexagonal socket is preferable to a 12-point socket. If a 12-point socket is used extreme care must be taken to keep it seated on the shell hexagon or burring and mutilation of the hexagonal surface will result. A fiber liner of the proper diameter in the socket will help prevent angling of the socket and damage to the shell and "hex" of the plug. Plugs should be installed at torques of not more than 500 in.-lb (approximately 40 ft-lb). It is impractical to use torque measuring wrenches for the installation of plugs in all locations of any particular engine. However, the frequent use of such wrenches in those locations where it is practical is desirable to develop and maintain the *feel* of the proper torque. A wrench handle longer than 10 in. should never be used for the installation of spark plugs. Application of excessive torque will distort the shell and result in damage to the installation gasket and perhaps a change of the gap setting. The core nut should never be used for tightening or removing plugs as this will change the gap setting.

A soft copper gasket between the plugs and cylinder aids in cooling and preventing gas leakage. It should be smooth and free from

scores. Gaskets become hard after service and should be annealed for repeated use by heating to a red glow.

Maintenance of the Ignition System. At regular periods the ignition system should be inspected for proper installation and operation. Excessive disassembly for inspection is not warranted unless malfunctioning exists. Ignition harness connections should be checked for tightness. The ground cable to the ignition switch should be checked to guard against its becoming grounded. Should it become grounded the magneto will not function. The magneto breaker points should be checked for proper adjustment and for pits or burns. Any oil or grease in the breaker point compartment should be cleaned out by means of a small brush or rag dipped in clear unleaded gasoline. Never use carbon tetrachloride or leaded gasoline for this purpose.

Magnetos are generally equipped with ball bearings which do not require any lubrication between overhauls. The breaker point cam follower is usually lubricated by a small felt partially soaked in oil. If, at inspection, oil appears on its surface when squeezed with the fingers, more oil should not be added. However, if it is dry, it should be moistened with a few drops of S.A.E. No. 10 oil. If too much oil is added it will be thrown off during operation. Plunger-type cam oilers should never be depressed while the cam is revolving. Excessive oil will be collected by the cam and thrown off into the compartment. Oil between the contact points causes burning and pitting.

The wear of the breaker points is normally balanced by the wear on the cam follower. Hence, the spark timing remains at approximately its original setting. A faulty condenser or deposits of oil on the breaker points will cause excessive burning of the points; lack of lubrication on the cam will result in excessive wear of the cam follower. If the wear at either of these locations exceeds the wear at the other, a change of spark timing will result. An appreciable change of spark timing will be indicated by excessive drop in horsepower output, when the engine is checked on each magneto singly. When such an indication occurs, after the spark plugs and ignition harness leads and connections have been examined, the magneto breaker points should be inspected and the timing checked.

When checking the timing of the breaker points or inspecting them for any reason, the breaker main spring should not be raised beyond a point giving $1/16$-in. clearance between the points. Any further tension on the main spring caused by raising it beyond this point may weaken it, thereby resulting in unsatisfactory magneto performance.

Should contact points be pitted or burned the breaker assembly

should be removed from the magneto and the breaker points disassembled for dressing. A suitable block for holding the face of the points level against the dressing file or stone is necessary for proper smoothing and polishing. Dressing of breaker points may be accomplished with a smooth flat oil stone or with No. 400 to 600 " wet-or-dry " paper. Emery cloth should not be used.

If contact points are not properly adjusted, if a set of contacts is to be reinstalled after dressing, or if a new set of contacts is to be installed, the procedure will not require the retiming of the magneto to the engine, but it will require the timing of the breaker points to the engine. Before the magneto was originally timed to the engine, the breaker points were timed to the magneto to open at the correct instant for best spark or, in other words, they were timed to give the correct *E* gap. The timing of the magneto with the engine has not been changed; so, if the breaker points are timed to open when the piston of No. 1 cylinder is at its full advance firing position, the points will also be timed with the magneto to give best spark. By using a piece of cellophane, as previously described, one may check the opening of the breaker points as the crankshaft is turned in its normal direction of rotation to the full advance spark position of No. 1 cylinder. Provisions are made for adjusting the complete breaker point assembly (or for adjustment of the stationary breaker point on some types of magnetos) to obtain the correct opening time of the points. It should be borne in mind that adjusting the breaker assembly or moving the stationary point in this instance does not alter the voltage output of the magneto so long as the points are set to open when the piston of No. 1 cylinder is at full advance firing position and the magneto timing with the engine has not been changed. Actually, in this instance, the breaker points are being timed to the magneto using the full advance firing position of the piston of No. 1 cylinder as the reference mark. After timing is complete any timing marks or symbols on the magneto for timing the points to the magneto should be noted as a double check on the timing.

If malfunctioning of the engine is traced to the ignition system, the exact cause of the trouble should be pursued further by beginning at the spark plugs. Spark plugs are often blamed for considerable trouble for which they are not responsible. When a plug is changed, the trouble which is not attributable to the plug may be temporarily cleared up, and the plug will be considered responsible for it. However, the plugs are often at fault, and since it is easier to check them

than any other part of the system, they are always checked first, unless some other cause is obvious.

Trouble causing malfunctioning may be traced to one of the two magnetos, the front or rear spark plugs, or their respective ignition wires by operating the engine on each magneto singly. At low engine speeds an accurate indication of ignition system efficiency when operating on one magneto cannot be obtained. It is necessary to run the engine at approximately 70 per cent of normal rated power to obtain an accurate indication. However, running on one magneto at high power will result in severe detonation and, therefore, the check must be made in the shortest practicable time. The normal drop in rpm, when switching to single magneto operation, varies in different engines, between left and right magnetos, and with the rpm at time of switching. It will be necessary to determine the normal drop for each engine installation. An increase of 50 per cent over this normal drop is an indication of excessive ignition system efficiency loss.

After determining on which magneto the engine is malfunctioning, provided it is only one, the trouble must be pursued still further by determining which cylinder or cylinders are not firing. One method of checking is to feel the cylinders or their exhaust pipes after running the engine on the magneto on which the trouble occurs. A cold cylinder indicates that it has not been firing. Having determined the cylinder or cylinders which are not firing, the spark plugs should be removed and tested.

When starting a cold engine an excessive amount of oil in the cylinders may foul the spark plugs. This is especially true of the cylinders of an inverted engine or the lower cylinders of a radial engine. Running engines at slow speeds for long periods of time, either on the ground or in the air, may cause fouling of the plugs. Engines consuming excessive quantities of oil have a greater tendency than others to foul plugs. New or overhauled engines which have been treated for storage have a heavy oil or grease within the cylinders to prevent rust. Draining will not remove all of this and it may foul the plugs. The cooling of the engine after stopping may cause water to condense between the gaps of the plugs, thereby causing fouling. Fouling from the above causes can usually be cleared out of the plugs by operating the engine at normal rated power for short periods of time. If this does not clear out the plugs they should be removed and inspected. Washing with clear unleaded gasoline will usually remove any oil,

grease, or dirt from the plug. Before reinstallation the plug should be allowed to dry and should be bomb-tested.

Besides the common carbon fouling encountered in spark plugs, there is also a *lead fouling* which is encountered in engines using anti-knock gasolines treated with tetraethyl lead. Lead from the fuel mixture deposits on the plug insulation and tends to short out the plug in the same manner as carbon. Under the heat of operation electrodes expand. This expansion opens up the mica washers and allows lead to penetrate between the laminations. Sufficient deposits of either lead or carbon may cause direct shorting across the gaps.

During damp weather, or when the humidity is high, or when temperature decreases, as during throttled descent, condensation may occur throughout the entire ignition system. When plugs are removed for inspection the wires and terminal sleeves, as well as the inner shell of the spark plugs, should be inspected for moisture. If moisture has been providing a path for grounding at the terminal sleeve or inserted wire, it may sometimes be detected by a fine irregular line on the surface of the sleeve or wire. Grounding of the ignition wires elsewhere will have to be checked with a high tension current. There are several instruments which may be used to provide the high tension current for checking the insulating strength of the wire covering. One of these is an ignition harness test set manufactured by the B. G. Corporation of New York City. Another is the "Megger," manufactured by the James G. Biddle Co. of Philadelphia.

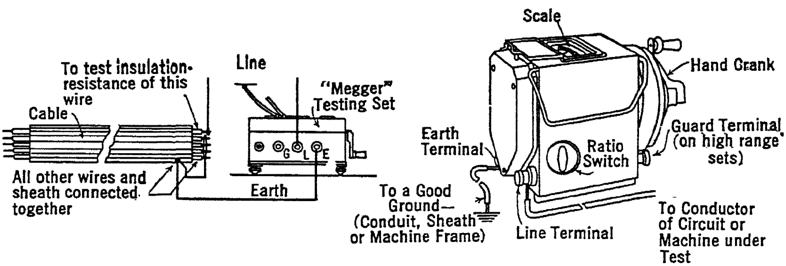
Courtesy The B.G. Corporation

FIG. 149. Ignition harness test unit.

The B. G. test unit is designed to produce a high voltage approaching the normal magneto voltage. The ignition wire is removed from the spark plug and the terminal sleeve is placed a sufficient distance from the engine to prevent arcing to it; then one side of the circuit is connected to the ignition wire to be tested at the magneto end, and the other side of the circuit is connected to the ignition shielding. When the current is turned on a leakage from the ignition

wire to the shielding will cause a light in the circuit to burn. In the event that distributor blocks are not removed while testing, care must be taken to prevent arcing within the magneto.

The " Megger " produces its own current by use of a hand-operated generator. An ohmmeter is incorporated in the instrument for the measurement of resistance. A perfect insulator would have an infinitely high resistance. However, there are no perfect insulators and the insulation cover on an ignition wire will have a certain measurable resistance. This resistance may be measured by connecting the " Megger " to the ignition wire and shielding as above. A resistance of 30 megohms is an indication that the insulation has sufficient dielectric strength to insure proper operation. A resistance of less than 30 megohms indicates that sufficient current will leak from the wire to the grounded shielding to prevent an adequate voltage at the spark plug electrodes.



Courtesy James G. Biddle Company

FIG. 150. The " Megger " insulation tester. It is not necessary to connect the ground wire to all other wires except the one being tested in the test of ignition harness. Connect ground wire to shielding only.

There is one type of insulation failure which the " Megger " will not indicate. If the conducting path being tested is not continuous the " Megger " does not have sufficient voltage to jump an appreciable gap and therefore will not indicate whether or not a higher voltage would follow the path. However, such conditions are very infrequent as the insulation usually loses its dielectric strength gradually throughout. A clean hole or cut in the insulation is an example of a failure which the " Megger " would not indicate. Such a failure would only be apparent when testing with a high voltage current capable of jumping from the wire to the ground at the hole or cut. There are several models of the " Megger." One which will produce at least 1000 volts should be used in testing ignition wires.

One fairly good method of testing ignition cables for short circuit

due to faulty insulation of the cables is to use a booster magneto. One terminal of the booster magneto is connected to the ignition wire at the distributor block electrode and the other terminal is connected to a ground on the engine. The spark plug end of the ignition cable is held about 3/8 in. from a suitable ground. If a good spark does not jump across this gap, the cable should be examined for faulty insulation.

In the methods just described for testing the insulation of ignition cables, no provision has been made to determine whether or not grounding may be occurring at the terminal sleeve, since the sleeve was not surrounded by a ground during these tests. But, during any of these tests the terminal sleeves may be surrounded by a ground and tested. Perhaps the best method of surrounding the sleeve with a ground is to install it in an ordinary spark plug from which the ground electrode has been removed. The removal of the ground electrode of the spark plug is necessary to prevent arcing to the ground at the spark plug gap.

If the ignition wire or wires are grounded out by moisture, temporary elimination may sometimes be affected by thoroughly drying the wires with hot air. Small electric blowers with an internal heating coil are often used for this purpose. This relief is only temporary, though, and the trouble will recur when the wires again become moist.

Grounding at the end of the wire which goes into the terminal sleeve is sometimes eliminated by cutting off a section of the end of the wire and rethreading the new tip into the terminal sleeve. When this method is used it must be possible either to pull up through the shielding a length of wire equivalent to the length cut off, or to peel the shielding back a distance equal to the length of wire cut off. On some ignition harnesses the section of wire from the spark plug to the central manifold may be replaced as a unit.

When only one or a few cylinders are not firing it is most probable that the trouble is in the spark plugs or ignition harness rather than the magneto. A failure of all cylinders to fire, irregular operation of all cylinders, low horsepower output, loud exhaust and overheating of the engine, detonation and backfiring, and difficult starting may all be caused by the magneto. Troubles and their causes which may occur in the magneto are listed below:

1. Trouble: *Engine fails to start.*
   Cause:
   a. Open or grounded secondary circuit (including distributor finger and brush).
   b. Open or grounded primary circuit.

c. Shorted condenser.
d. Grounded ignition switch wire.

2. Trouble: *Irregular operation of all cylinders, hard starting, low horsepower output, and occasional red exhaust flame.*

Cause:
a. Weak magnets.
b. Burned, pitted, or dirty contact points.

3. Trouble: *Low horsepower output, overheating of engine, and loud exhaust with reddish flame.*

Cause:
Ignition timed too late.

4. Trouble: *Hard starting with backfiring, low horsepower output, and detonation.*

Cause:
Ignition timed too early.

If all ignition wires are removed from the spark plugs the magneto output may be checked by turning the engine over while one of the wires is held about ⅛ in. from a ground. A weak, thin spark is an indication of weak magnets or a partial ground. No spark is an indication of one of the causes listed under group 1 above. An inspection should be made of the ignition switch wire, the contact point spring, and such of the primary and secondary circuit wiring as is visually possible. Shorting of the ground wire may be tested by running the engine with the ground wire disconnected at the magneto. To shut off the engine it will be necessary to cut off the fuel supply. It will be remembered that the magneto is " On " when the ground circuit is open.

A " Megger " will be of aid in testing the primary and secondary circuits for a ground or open circuit and also for testing the condenser for a short. The correct resistance of the secondary winding and of the primary condenser is specified in the magneto manufacturer's service manual. Condensers should be tested while they are at a temperature corresponding approximately to their normal operating temperature, which is about 200°F. They may be brought up to this temperature by heating in an oven.

Care and Handling of Spark Plugs. Spark plugs are replaced at intervals varying up to and sometimes above 100 hr of operation. The interval will be determined by operating conditions and service experience, and should be such that the plugs are removed before they commence malfunctioning. An inspection of the plugs as they are removed from the engine will frequently reveal the condition of the engine. A heavy layer of soot or carbon on the electrodes indicates

that piston rings may be worn or stuck and that high oil consumption may have been experienced. If the electrodes are clean but discolored and appear to have been running hot, this may be due to detonation from poor fuel, to operating at too high engine output, to excessively lean mixture, a loose spark plug, or a loose plug core. Plugs which have a brownish gray or tan-colored core are satisfactory. A deposit of fused lead oxide, colored ash-gray, on the insulation of the firing end of the core is a sign of overheating.

Spark plugs which have been removed from an engine should always be inspected and tested, but it is not always necessary nor even desirable to disassemble the plugs. If a plug has been functioning improperly it should be checked for the proper gap clearance and reset if necessary. Moderate amounts of oil and grease may be removed with clear unleaded gasoline. Do not allow plugs to remain more than a few minutes in gasoline as the gasoline will have a tendency to seep between the layers of insulation and may carry dirt or carbon with it. Gasoline will only remove oil and grease from the plugs. It will not remove deposits of hard carbon or solid matter. Carbon tetrachloride or leaded gasoline should never be used for cleaning plugs.

After a few minutes operation in an engine, plug ends may have a blackened appearance. In the absence of lead and oil deposits this blackening is not detrimental to the operation of the plug.

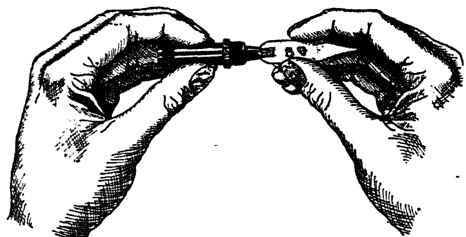
It is good practice to disassemble plugs which were operating satisfactorily at removal only at every second periodic removal period. If this procedure is followed, it will be necessary to use some method of marking the plugs to indicate whether they were disassembled or only cleaned, reset, and tested at the last removal. This is easily done by painting a designating mark on the core shell.

Disassembly of plugs should be done with the proper tools to prevent damage. After disassembly and cleaning with unleaded gasoline or acetone, the hard carbon deposits and solid matter may be removed by use of No. 00 sandpaper or No. 150 Aloxite. Sandblasting, metal buffing wheels, carborundum, steel wool, or emery should never be used for cleaning portions of plugs containing mica insulation. Particles of such material may become imbedded in the mica insulation and cause insulation breakdown.

Burning or pitting of the core electrode tip should be removed by shaping the tip to a smooth cylindrical contour. Satisfactory gap adjustments cannot be made when the size of the core electrode tip has been reduced too much. Fig. 151 shows method of checking the B. G. plug for minimum electrode diameter. Broken, flaked, or

dented portions or holes in the mica insulation are causes for rejection of the affected portion of a plug.

Shells and parts of plugs not incorporating mica insulation may be cleaned with a knife, wire brush, or steel wool. For large quantities liquid cleaners are available. The shell or outer electrode tips should be smoothed like the core electrode tips. After cleaning, metal portions of the plug should be covered with a film of light oil or rust inhibitor such as "No-ox-id." Polishing the mica of the core nose with beeswax will prevent moisture penetration while in storage.



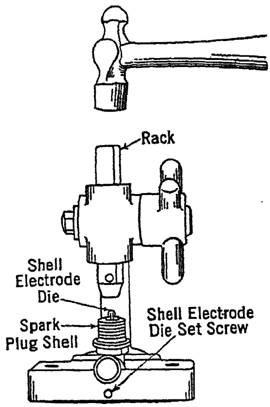
Courtesy The B. G. Corporation

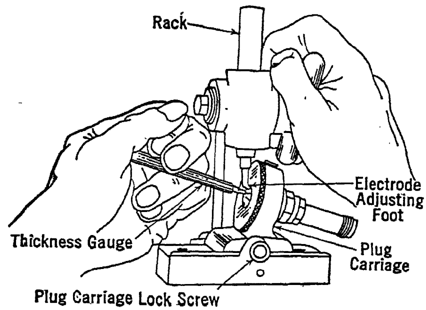
FIG. 151. Checking electrode tip diameter.

Where large quantities of shells are to be cleaned, it is economical to use some type of liquid cleaner. Two types of salt baths which may be used are (1) Heatbath Penetrate No. 1 (manufactured by the Heatbath Corp., Springfield, Massachusetts) or (2) a mixture of equal parts of commercial sodium nitrate and potassium nitrate. The former will clean shells thoroughly in from 5 to 10 min and the latter requires about 30 min. The salt bath must be at a temperature of approximately 950°F. The shells should be contained in a perforated basket while in the bath, and after cleaning should be allowed to drain and cool for 10 to 15 min, and then immersed in clear water. Steam and water will be spattered if they are immersed too soon. After cooling the shells should be rinsed thoroughly to remove all traces of the salt. Magnus No. 64 (manufactured by Magnus Chemical Co., Inc., Garwood, New Jersey) is a very good shell cleaner and does not require as high a temperature as the salt baths. A temperature of 212°F is sufficient and may be attained by a steam coil in the bottom of the cleaning vat.

If the surfaces of the center and outer electrodes are formed so that a uniform gap distance is maintained between them, electrode burning is more uniform, less frequent gap setting is required, and longer electrode life is obtained. To make the shell electrode conform to the curvature of the core electrode, for insurance of uniform clearance between the surfaces, the shell electrodes are correctly formed with a special shell electrode forming tool. Fig. 152 illustrates the shell electrode forming tool for use with B. G. spark plugs. The same tool may be arranged for adjusting the shell electrodes to give the

proper gap clearance as shown in Fig. 153. The proper thickness gauge is inserted and then pressure is exerted on the shell electrode until a snug fit exists between the thickness gauge and the center electrode. Each shell electrode must be adjusted in a similar manner. The proper gap clearance must be obtained from the manufacturer. Clearances are seldom under 0.012 in. and will average close to 0.015 in.





Courtesy The B. G. Corporation

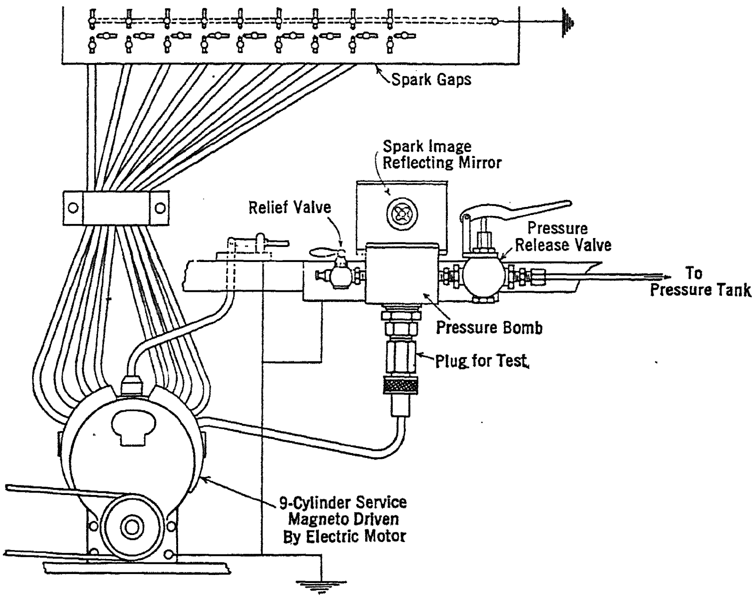
FIG. 152. Forming the shell electrode.

FIG. 153. Adjusting electrodes for the proper gap.

A plug cannot be tested properly for sparking in the open air. As pressure increases, more voltage is required to jump a specified distance. Therefore, to test a plug under conditions comparable to those under which it must operate in the engine, it is necessary to test the plug under a pressure higher than atmospheric. The pressure testing of plugs is commonly called bomb testing.

Air or some inert gas such as carbon dioxide or nitrogen is used for supplying pressure for the bomb test. If compressed air is used, provisions should be made for removing moisture from the air before it enters the bomb as the presence of moisture will give misleading results. A test bomb installation is shown in Fig. 154. The test bomb has a threaded hole into which the plug is screwed. A glass window is located so that the electrodes may be observed. A pressure gauge is installed to indicate the pressure within the bomb. A standard service type of magneto is used to provide the current. Spark coils should not be used for testing mica plugs. All leads from the magneto, except the one leading to the test bomb, should be provided

with gaps to dissipate their energy and prevent flashover in the magneto. The magneto should be run at a speed to give about 1000 sparks per minute to the test bomb lead. A switch is installed in the magneto primary circuit to control the spark.



Courtesy Aero Spark Plug Company

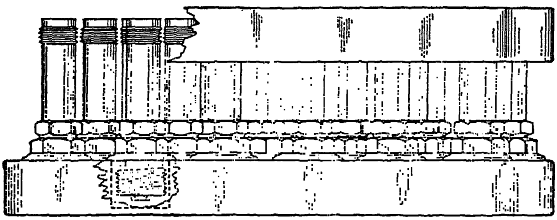
FIG. 154. Spark plug bomb test installation.

A test pressure of 125 lb per sq in. with gaps not exceeding 0.015 in. is satisfactory for plugs used in the low horsepower engines. For engines with high specific power output, 150 lb per sq in. is generally used. Occasionally higher pressures are employed. The engine manufacturer's recommendation on bomb test pressures should be adhered to. Plugs should be permitted to spark under pressure for approximately 15 sec. Practice is required to determine whether a plug is firing regularly. Hunting of the spark from one position to another may give the appearance of missing.

Unfortunately, the lead fouling, caused by coating and impregnation of the plug insulation by conductive compounds from leaded fuel, cannot be readily determined by the ordinary bomb test. The lead compounds have a relatively high resistance at normal temperatures, but become better conductors as their temperatures rise.

Hence, a plug may test satisfactorily in the test bomb, but begin to "cut out" as the temperature rises when installed in the engine. A special test unit, using an electrolyte solution which makes the lead deposit a good conductor at ordinary temperatures, has been developed by the U. S. Bureau of Standards. This unit, called a "Nafotel," is simple to operate and is distributed by Aero Spark Plug Co., Inc., New York City.

Spark plugs should be handled and stored with care. Every caution should be taken to prevent damage or misadjustment of the electrodes. Small wooden trays similar to the one shown in Fig. 155 will be of aid in preventing damage to the electrodes.



Courtesy The B. G. Corporation

FIG. 155. Spark plug storage and shipping tray.

To avoid the effects of moisture, plugs should be stored in a dry place. A cabinet heated with light bulbs is a convenient means of insuring dryness. When electric current is not available an airtight cabinet may be used in which a dehydrating agent, such as an open can of anhydrous calcium chloride, is provided. The calcium chloride will have to be replaced or dehydrated periodically.

CHAPTER VIII

INSTRUMENTS

Certain instruments are necessary to insure the safe, economical, and reliable operation of the aircraft power plant. Of those physical quantities whose measure indicates the operation of the engine the most important are:

1. Oil pressure and temperature.
2. Fuel pressure.
3. Manifold pressure.
4. Cylinder temperature.
6. Crankshaft revolutions (rpm).
7. Inlet air temperature.
8. Fuel-air mixture ratio.

Through the use of instruments these physical quantities are measured and indicated on dials in the cockpit. With a familiarity of the engine operating characteristics the pilot or mechanic may identify correct operation from the instrument readings. In the event of incorrect engine operation, the mechanic should be able to use the instrument readings intelligently for diagnosis of troubles.

Construction. Power plant instruments are made with dial diameters of two standard sizes, 1⅞ and 2¾ in. The cases are made of either a molded phenolic compound or of aluminum alloy. Lugs fitted with threaded brass inserts for receiving the mounting screws are inserted in the case. Sensitive differential pressure gauges and absolute pressure gauges require an airtight case. Other instruments only require a raintight case to keep out moisture and dust, and may be identified by a small hole located in the bottom of the case.

The dial graduations, numerals, and pointers are painted with a luminous paint which makes reading in the dark possible. Luminous paint is very dangerous unless properly handled, and should be applied to instruments only by persons familiar with its use. Some instruments are provided with individual lighting. Several different methods of individual lighting are in use.

The maximum and minimum operating limits for various operating conditions are prescribed by the engine manufacturer. So that the pilot may readily know when he is within these limits, varicolored operation markings are painted on either the instrument cover glass or the dial itself. If the cover glass is painted, an indexing line should be painted on the glass and case at the bottom of the instrument to indicate any movement of the glass. Short radial lines, usually red, are used to indicate maximum and minimum limits. Arcs of circles are used to indicate the range of various operating conditions, green usually being used for the desired cruising condition range and yellow for the permissible continuous operation range. Some of the later types of instruments are provided with adjustable colored markers to indicate the operating limits. These colored markers may be set as desired and locked in place without disturbing the cover glass.

General Instrument Maintenance. The overhaul and repair of instruments is a delicate and highly specialized job requiring skilled personnel and proper overhaul and test equipment. Still, there is a certain amount of maintenance and inspection which must be performed while the instruments are installed in the aircraft and for which the engine and airplane mechanics are responsible. Various instruments will require special maintenance procedure, which will be discussed under appropriate headings, but in general the routine maintenance required on all instruments is as follows:

Daily Inspection

1. Clean and inspect condition of cover glasses.
2. Check operation of instrument lights.
3. Check the zero or normal reading of pointers. Thermometer instruments should indicate the surrounding temperature. Absolute pressure-operated instruments should indicate the surrounding pressure.
4. With the engine running check instrument pointers for excessive oscillation.
5. With the engine running check the readings for consistency with engine requirements.

Fifty-Hour Inspection

1. Check lines and connections for leaks.
2. Check all electrical and bonding connections for good contact.
3. Inspect mounting screws and brackets of instruments and dependent units.
4. Inspect operation markings for discoloration and correctness.
5. Inspect vibration absorbers for proper attachment and tension.

If an instrument is found to be operating improperly and the reason is not obvious, a check should be made of all lines and connections or wiring for continuity before the instrument or its dependent unit is removed from the aircraft. Instruments are delicate mechanisms and should be handled with great care during removal and installation. When replacing an instrument one of like kind should always be used unless it is definitely known that another type will operate satisfactorily. An instrument thread compound should be used on all threaded tube connections, and care must be taken not to exert too much force when making connections at the instrument case or else a broken case will result.

PRESSURE GAUGES

Fuel Pressure Gauge. The purpose of the fuel pressure gauge is to indicate the difference between fuel pressure and air pressure at their respective inlets to the carburetor. Gauges to be used in conjunction with externally supercharged engines have two connection nipples marked " Fuel " and " Air." The air connection vents the case which is otherwise airtight. The fuel connection is to the Bourdon tube of the gauge. When used with externally supercharged engines the air vent connects to the air pressure chamber of the supercharger. On internally supercharged engines it is only necessary to vent the case with the air pressure in the cockpit since it is substantially the same as the air pressure at the carburetor intake. Hence, it is only necessary to use a raintight case with the conventional vent hole or if a gauge with an air nipple is used to leave the air connection open to cockpit pressure. Only the fuel connection need be made.

The fuel pressure gauge utilizes the Bourdon tube mechanism. The principle of operation, as will be explained, applies to all pressure gauges utilizing the Bourdon tube, the chief difference between various gauges being in the size and stiffness of the Bourdon tube. As the pressure range of the gauge is increased a stiffer Bourdon tube is used.

The Bourdon tube is a hollow tube formed in an arc and closed at one end. The other end, which is held stationary, opens to a connection which receives pressure. As pressure is applied internally the tube tends to straighten out. The forces resisting the straightening out of the tube are the air pressure on the outside of the tube and the natural resistance of the tube to bending. With the natural resistance to bending and the spring quality of the tube, the gauge is a differential pressure-measuring device, measuring the difference between the pressure inside and outside the Bourdon tube. The movement of the

tube is proportional to the difference in pressures and causes a movement of the links, levers, pinions, and pointer as shown in Fig. 156.

A restricted fitting with a small hole, usually a No. 60 drill (0.04 in.), is used to connect the fuel pressure line at the carburetor. The small hole is to prevent excessive leakage of fuel in event of failure of the fuel pressure line. Fuel pressure gauge lines are not necessarily always connected directly to the carburetor, but may be connected with some other line which is connected to the pressure inlet of the carburetor, such as a cross-feed fuel line.

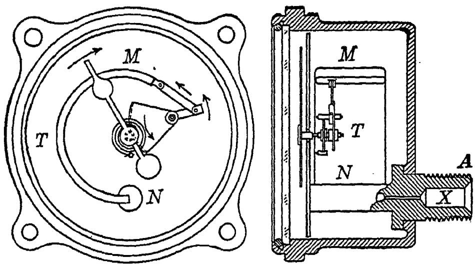
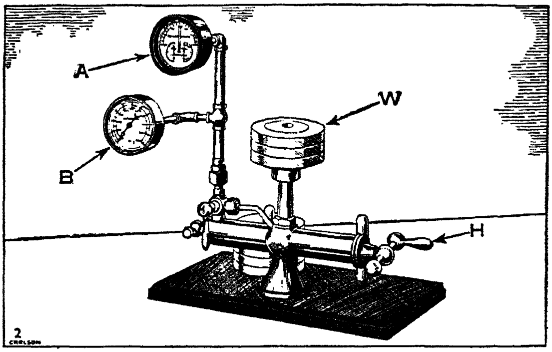


FIG. 156. Pressure gauge utilizing the Bourdon tube mechanism.

On installations where the pressure gauge is mounted considerably above the carburetor level, the gauge will not read the true pressure at the carburetor if the gauge line is filled or partially filled with fuel. The column of fuel in the gauge line exerts a downward pressure which cancels a portion of the pressure at the carburetor. There may be a pressure of, say, 3 lb per sq in. at the carburetor, but there may be enough fuel in the gauge line to exert a downward pressure of 1 lb per sq in. and result in a reading of only 2 lb per sq in. at the cockpit gauge. A column of fuel 3.3 ft high exerts a downward pressure of approximately 1 lb per sq in.

A pressure gauge line which is not absolutely airtight will allow air to escape and fuel to fill the line; this will result in an incorrect reading at the cockpit gauge. Some fuel installations utilize the pressure gauge line as a primer supply line. When the primer is used the gauge line is filled with fuel. If the primer is not used often, air leakage at the primer may allow fuel to drain and air to fill the line again. In such an installation it will appear that the fuel pump or fuel system relief valve is not maintaining a constant fuel pressure, whereas the pressure at the carburetor may be remaining constant and the error is in the pressure gauge reading.

Fuel pressure gauges require no special maintenance. If the accuracy of reading is doubted the gauge may be tested against a standard gauge of known accuracy. Accuracy of reading may be more definitely determined by testing on a dead weight tester as illustrated in Fig. 157. The unit to be tested is put on the pressure connection *A*.



Courtesy Kollsman Instrument

FIG. 157. Dead weight pressure gauge tester.

A standard gauge may be put on the connection *B*, or the pressure may be measured by the weights *W*. Pressure is put on the apparatus by turning the hand wheel *H*.

Oil Pressure Gauge. The purpose of the oil pressure gauge is to indicate the pressure at which the lubricating oil is being furnished to the engine. The gauge is similar in construction to the fuel pressure gauge and uses the Bourdon tube mechanism. The case is raintight and vented to the atmosphere, and there is one nipple connection which connects to the oil pressure line from the engine. At the engine the gauge line connection is made on the pressure side of the oil pump. It has been noticed on some installations that the pressure connection is made on the inlet side of the oil strainer. With such an arrangement a true indication of the pressure furnished the engine is not possible if the strainer is dirty and clogged.

To prevent excessive leakage in the event of gauge line failure a restricted fitting is used at the gauge line engine connection. The hole in the fitting is usually a No. 60 drill (0.04 in. in diameter). This restriction also helps to prevent surging of the gauge. There is also a small restricted inlet hole at the gauge to aid in preventing surging. If the surging action at the oil pump is not sufficiently dampened by the two restricted holes to prevent excessive oscillation

at the gauge, a surge chamber may be installed in the gauge line. The air in the surge chamber (Fig. 158) acts as a cushion, smoothing out the hammering effect and preventing oscillation at the gauge.

During cold weather the oil becomes very thick in the gauge line. With the thick oil and restrictions in the line the gauge may not register any pressure when the engine is first started and will be very slow in registering any pressure at all. To prevent this, the gauge

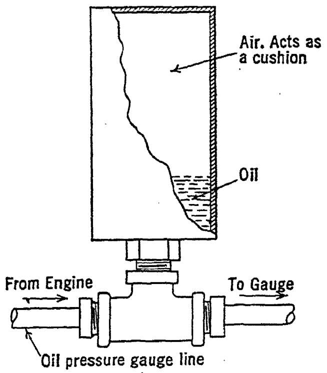


FIG. 158. Surge chamber in oil pressure gauge line.

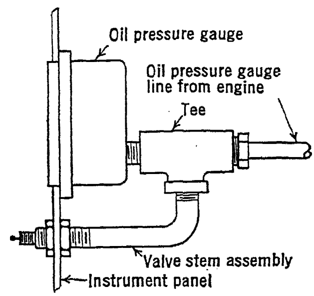


FIG. 159. Oil pressure gauge line filler connection. (Permits filling of gauge line with light oil without disconnection of line at the gauge.)

line should be filled with light oil of about S.A.E. No. 10 viscosity. The gauge line should be disconnected at the gauge and the line should be pumped full of light oil. It will be necessary to refill the line about every 100 hr of engine operation. To facilitate filling the gauge line a filler connection as shown in Fig. 159 may be installed at the gauge. A pump equivalent to a bicycle hand pump is adequate for filling the line.

Because of the proximity of the engine gauge line fitting to circulating oil, a carbon deposit tends to build up around the restricted outlet hole. This deposit may build up sufficiently to completely close off the pressure outlet. If the restriction cannot be cleared by pumping light oil or blowing compressed air through the gauge line, it will be necessary to remove the fitting and clean the hole with a drill of proper size.

Fuel and Oil Pressure Warning Units. Fuel and oil pressure warning units are designed to close an electrical circuit which operates a light or other signal and thereby warn the pilot that the fuel or oil pressure has dropped below a certain point. Warning units utilize either a Bourdon tube mechanism or an expanding and contracting

diaphragm. The movement of the Bourdon tube or diaphragm actuates a switch when the pressure falls below a predetermined value. The pressure at which the circuit is closed may be adjusted by means of an adjusting screw, which is locked in place by a lock screw or nut after the setting is made. Units using Bourdon tubes may be adjusted while the unit is installed. Some diaphragm-type units must be dismounted for adjustment. Before installation the units should be adjusted for the proper setting with a battery and lamp and dead weight tester or standard gauge.

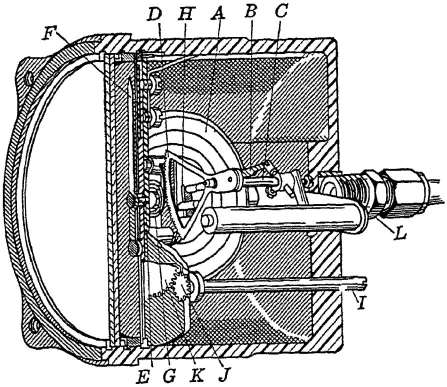
The warning units are connected to the fuel and oil pressure gauge lines. The fuel warning units may be checked for proper setting by operating the wobble pump and noting the fuel pressure on the cockpit gauge when the signal goes on or off. The oil warning unit setting may be checked by noting the oil pressure at which the signal goes off as the oil pressure builds up after starting the engine.

Manifold Pressure Gauge. The mass (weight) of air taken into a cylinder on the suction stroke of the piston is dependent upon the air pressure and temperature at the cylinder inlet port. Also, it is dependent upon the residual gases left in the cylinder after the last exhaust stroke, the amount of residual gases decreasing as the pressure at the exhaust port decreases or, in other words, as altitude increases. The horsepower output of an engine is almost directly proportional to its rate of mass (weight) air consumption. The rate of air consumption is dependent upon the amount of air taken in each suction stroke and the number of suction strokes per unit of time. Therefore, if the inlet pressure, inlet temperature, exhaust pressure, and rpm of the engine are known, the horsepower output may be determined. Power charts (see Fig. 258) are furnished by the engine manufacturer for the determination of power output using these data.

The manifold pressure gauge is used for measuring inlet pressure at the cylinder inlet port. On unsupercharged engines it is not necessary to use a manifold pressure gauge since the rated take-off power cannot be exceeded at any altitude. However, on supercharged engines it is possible below the rated altitude to exceed the rated take-off power. To prevent such an occurrence a maximum manifold pressure, corresponding with rated take-off horsepower, is specified by the engine manufacturer and should never be exceeded. The manifold pressure is controlled by the amount of throttle opening, more opening being necessary to maintain a constant pressure as altitude increases.

The manifold pressure gauge consists of an evacuated diaphragm assembly A (Fig. 160), and a mechanism for multiplying its deflection. A link B transmits the movement of the diaphragm to the rocking-

shaft C, and the sector gear D, meshed with the gear of the hand-staff pinion E, transmits the motion to the hand assembly F. A hairspring G removes the backlash in the mechanism and a bimetallic strip H compensates for temperature changes. This particular instrument is provided with an adjustable operation-marking sector. Adjustment is made by turning the shaft I whose gear J meshes with the gear K on the sector dial assembly.



Courtesy Kollsman Instrument

FIG. 160. Cutaway view of manifold pressure gauge.

The case is airtight and is connected with the manifold pressure gauge line by a connection in the rear of the case. Thereby, the pressure at the intake manifold is always maintained inside the case. A restriction at the pressure inlet fitting prevents rapid fluctuations of pressure within the case.

As the pressure within the case increases or decreases the diaphragm assembly contracts or expands. This deflection is transmitted to the pointer. The instrument is calibrated to indicate absolute pressure. If there were a complete vacuum within the case the pointer would read zero. It might be considered in effect an aneroid barometer. When the engine is not operating the gauge indicates atmospheric pressure, which is the pressure at the intake manifold.

The dial is graduated in inches Hg (inches of mercury). It might just as well be graduated in pounds per square inch or any other unit of pressure, but inches Hg has become standard. One pound per square inch equals 2.03 in. Hg.

Since the manifold pressure gauge indicates barometric pressure when the engine is not operating, it may be checked for correct reading in that range by comparison with some other barometric instrument reading. The airplane altimeter is a very accurate barometric pressure measuring instrument and is handy for comparison. First, the pointer hands on the altimeter are set to zero, while the instrument panel is gently tapped. With the pointer hands at zero the barometric scale on the altimeter will show the local barometric pressure in inches Hg (or other units). The manifold pressure gauge reading should be correct within 0.4 in. Hg.

In the event of unsatisfactory operation of the gauge the gauge and lines should be checked before the instrument is removed. To check for leaks in the gauge line or instrument case, a suction is applied to the engine end of the gauge line and, while the hand of the instrument is being watched, the vacuum is shut off when the hand reaches the lowest point on the scale. If the hand returns to its zero position at a rate greater than 0.4 in. Hg per min the gauge line or case is not airtight enough. A check for a leak in the instrument case should be made by removing the gauge line from the back of the case and applying suction until the pointer again reaches the lowest point on the dial. If the rate of motion of the pointer is now within the limits specified above when the vacuum is shut off, the case may be considered airtight, and the leak located in the gauge line. Leaks in the line may be eliminated by tightening all connections and replacing porous tubing, unless a line or fitting is cracked; in this event it will be necessary to make a replacement.

To test the accuracy of the gauge throughout the complete range it is necessary to compare it with some standard, such as a gauge of known accuracy or a mercury manometer. To cover the complete range a pressure higher than the outside air, as well as a suction, will be necessary. Placing the complete instrument in a bell jar while testing will indicate the calibration but will not reveal a leaking case.

TEMPERATURE INDICATORS

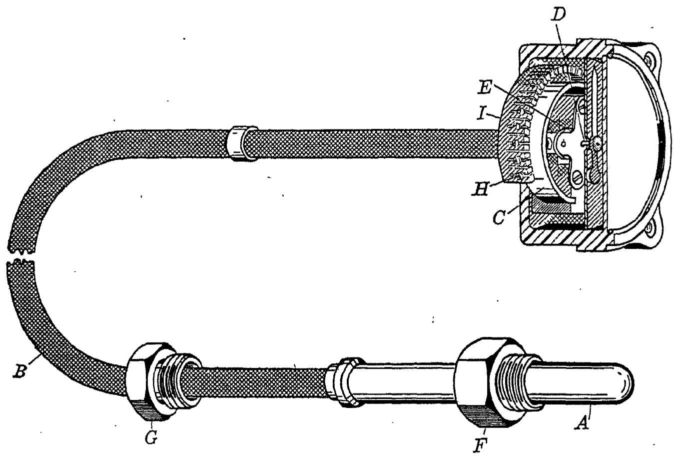
Temperature indicators are used for measuring and indicating the temperatures of:

1. *Engine lubricating oil.* This measurement is made at the engine oil inlet. Measurement is sometimes also made at the engine oil outlet.
2. *Cooling liquid in liquid-cooled engines.* This measurement is made at a point between the cooling liquid outlet and radiator inlet.
3. *Carburetor fuel-air mixture.* This measurement is made in the carburetor throat or carburetor to engine adapter.
4. *Free air.* This measurement may be made at one or several points in the cockpit, cabin, or at some external point on the airplane surface.
5. *Cylinders of air-cooled engines.*

Temperature measurements at the above points enable the pilot to operate the engine within the correct operating temperature limits. They also may serve as an indication or forewarning of certain engine troubles.

Vapor Pressure Thermometers. The vapor pressure thermometer consists of three units integrally connected; the bulb which is located at the point of temperature measurement, the indicator which is located in the cockpit, and the capillary tube which connects the bulb and the indicator. The bulb is hollow and is filled with a volatile liquid (usually methyl chloride). To provide more surface for contact with the air the free-air thermometer bulb is longer and formed in the shape of a helical tube. The capillary tube is made of a very small annealed copper tubing and is protected with a braided copper wire shield.

The indicator is essentially composed of a Bourdon tube assembly similar to that of any pressure gauge. A change of temperature of the bulb will cause a change of vapor pressure in the system, which



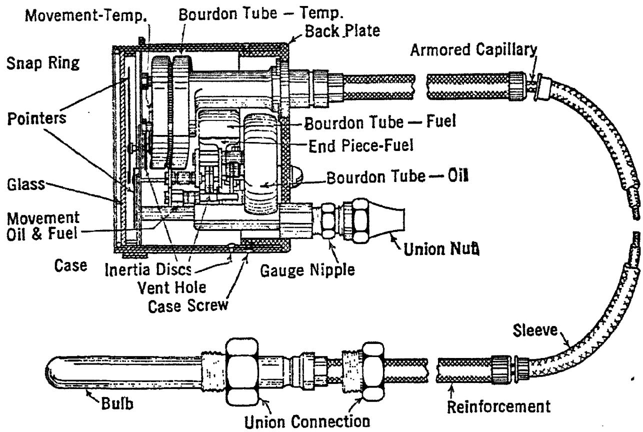
Courtesy Kollsman Instrument

FIG. 161. Vapor pressure thermometer.

in turn causes the Bourdon tube to expand or contract. Vapor pressure within the system does not rise in direct proportion to the rise in temperature, but at a greater rate. Hence, in order that an evenly divided dial may be used, it is necessary to provide a series of restraining screws *H* (Fig. 161) mounted in casting *I* which restrain the movement of the Bourdon tube. Without these restraining screws the dial would have to be graduated in uneven increments.

Sometimes a fuel pressure gauge, oil pressure gauge, and vapor pressure oil thermometer are combined within the same case. Such a combination is called an engine gauge unit. Each gauge in such a unit functions the same as if it were an independent unit.

Vapor pressure thermometers require no special maintenance. Installation is the important factor in the continued satisfactory operation of the thermometer. The capillary tube is delicate and extreme care should be taken not to bend or kink it when it is installed. The tube cannot be cut for shortening and any excess must be coiled and securely fastened to prevent vibration. As the tube is strung it should

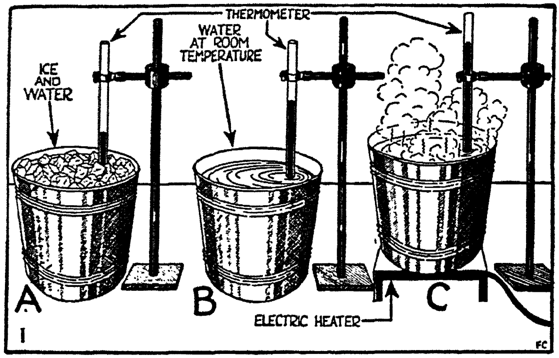


Courtesy Moto Meter Gauge and Equipment

FIG. 162. Engine gauge unit.

be taped securely to rigid members at points from 8 to 10 in. apart. A layer of tape should be placed around the tube and the member to which it is to be secured, to act as a cushion, before securing in place. Where the tube passes through the firewall or the like it should be protected with rubber grommets. At points where there is considerable relative movement between two members, such as between the firewall and a shock-mounted engine mount, the capillary tube should be looped when passing from one member to the other. Capillary tubes cannot be repaired or replaced economically and in event of failure it is necessary to replace the complete gauge assembly.

The calibration of any temperature-measuring instrument may be tested by using three or more buckets of water, which are kept at desired temperatures, and thermometers for measuring the temperatures (Fig. 163). Oil may be used instead of water for measuring the higher temperatures. The temperature of the liquid in one bucket may be kept near the upper end of the range of the instrument by an electric heater; that of another bucket at 32°F (0°C) by ice, and the third bucket may be at room temperature.



Courtesy Kollsman Instrument

FIG. 163. Apparatus for testing temperature-indicating instruments.

Electrically Operated Thermometers. Electrically operated thermometers are used for the same purposes as the vapor pressure thermometers. They have the advantage of requiring wires rather than a capillary tube for the connection from the bulb to the indicator. Through the use of a selector switch several " bulb " units may be connected with one indicator unit. They are dependent upon the airplane's battery generator system for current supply.

The principle of operation is based upon the fact that metals change in electrical resistance with change in temperature. This change in resistance changes the amount of current flowing in a circuit, which current is measured by an indicator calibrated in degrees of temperature. The temperature sensitive element or " bulb " is made up of a coil of pure nickel wire inserted in a protection tube and provided with suitable electrical leads.

There are two general types of indicators: those using a sensitive d'Arsonval mechanism and those using a ratio meter mechanism.

The d'Arsonval system utilizes the principle of the Wheatstone bridge, of which one arm is the temperature sensitive element. It will be seen in Fig. 164 that a voltage is applied at points $V(-)$ and $V(+)$ of the Wheatstone bridge. The resistances of A, B, and C are each 100 ohms. If the resistance of the bulb is 100 ohms, as it is at 0°C, then the current flowing from $V(+)$ to $V(-)$ through A and B is the same as the current flowing through C and the bulb. With the current flow the same through the upper and lower arms of the Wheatstone bridge there is no voltage difference between points X and Y. The indicating instrument records current flow, and, since in this case there is no current flow between points X and Y, the pointer reads zero.

As the resistance of the bulb changes with changes in temperature the circuit becomes unbalanced and there is a difference in voltage between points X and Y. This difference causes a flow of current through the instrument which indicates the amount of flow on a dial calibrated in degrees of temperature. The direction of flow between X and Y is dependent upon whether the bulb resistance is above or below 100 ohms. The instrument reads above or below the calibrated zero, depending upon the direction of current flow.

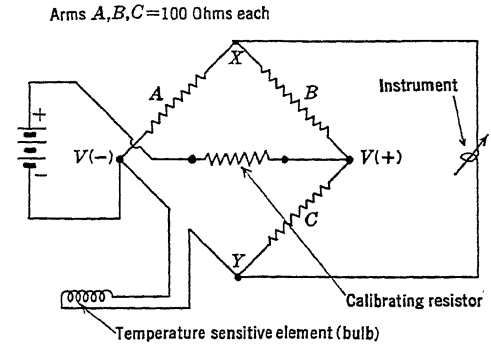


FIG. 164. Wiring diagram of an electrically operated thermometer.

The advantage of the ratio meter type of indicator is that its accuracy is not impaired by fluctuations in voltage. The indicator is constructed with two moving coils cemented together and mounted on a rotatable shaft which is supported between the pole shoes of a permanent magnet. The pointer is attached to one end of the shaft. The coils are connected in parallel as shown in Fig. 165. In series with one of the coils is a fixed resistance. In series with the other is the temperature sensitive bulb. The polarity of the magnet and the direction of current flow in each coil is such as to cause the coil carrying the greater current to move into the weaker magnetic field. With the bulb resistance the same as that of the fixed resistance R, the current flowing through each coil is the same, the torques balance, and the pointer remains in the vertical position. If the temperature of the bulb is raised, its resistance is increased with a resultant decrease in the current flow through coil C-1. With the current in coil C-2 now greater than that in coil C-1 there is a tendency for coil C-2 to move into a weaker field. As coil C-2 moves into the weaker field, coil C-1

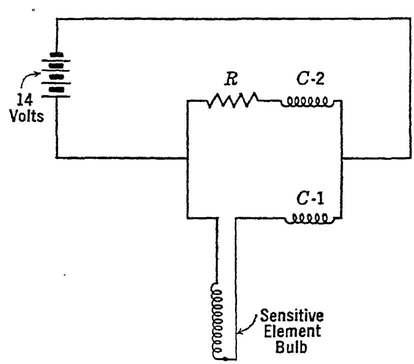


FIG. 165. Wiring diagram of ratio-type thermometer.

moves into a stronger field until the torques on each balance. The pointer, which is on the same shaft as the coils, moves across the dial which is calibrated in degrees of temperature. Conversely, a reduction in the temperature of the bulb would increase the current flow through coil *C-1* and cause the pointer to move in the other direction. Since the operation of the indicator is dependent upon the proportion of current flowing through each coil and not upon the total amount of current, relatively large fluctuations in voltage do not affect the accuracy of the instrument.

Electrically operated thermometers require no special maintenance procedure. The mechanical zero may be adjusted by an adjusting screw usually located on the face of the instrument. Make sure that the current supply is off when making the zero adjustment. Resistance bulbs require no special servicing. They will last indefinitely if not subjected to excessive heat. If the accuracy of a resistance bulb is doubted, it may be checked with an ohmmeter. For every temperature it has a definite resistance, which will be specified by the manufacturer. The accuracy of bulb and indicator over the complete range may be tested as outlined under *test for vapor pressure thermometers.*

When making replacement of indicators or bulbs, one should make certain that they are for matched operation. All bulbs are not of the same resistance.

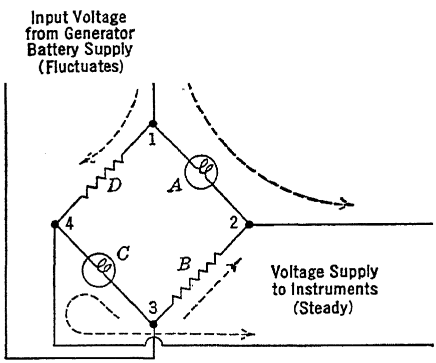


FIG. 166. Wiring diagram of voltage compensator.

Voltage Compensator. Although the voltage compensator is not in itself an instrument, it is used in conjunction with several electrical instruments whose accuracy of reading would be affected by fluctuations in their supply voltage. Within limits, the voltage compensator will supply a constant magnitude voltage even though its supply voltage fluctuates. The wiring diagram of the voltage compensator, which utilizes the Wheatstone bridge circuit, is illustrated in Fig. 166. The two resistors *B* and *D* and the two lamps *A* and *C* form the four arms of the Wheatstone bridge. The resistance of the lamps *A* and *C* increases as they rise in temperature with rise in input voltage.

By following the current path from one of the supply lines the principle of operation may be understood. The positive supply line enters the Wheatstone bridge circuit at point 1. The majority of the current passes through the lamp *A* and on to the instrument voltage supply. A certain amount of the current entering the bridge at point 1 passes through the resistance *D* to point 4 where it is in opposition to the negative voltage passing through lamp *C*. This opposition of current reduces the voltage to the instrument supply. Suppose now that there is an increase in the voltage input at points 1 and 3. Lamp *A* will rise in temperature with the rise in voltage. The rise in temperature increases the resistance of the lamp filament. However, this rise in resistance is not sufficient to prevent an increase in the current flow through lamp *A* with the increase in voltage. But, the current flow through resistance *D* also increases, and at a rate greater than through lamp *A*; this gives a greater opposition to the negative voltage at point 4. Thus, with the opposition at point 4 increasing at a greater rate than the increase of flow through lamp *A* with the increase in voltage input, a constant instrument supply voltage is maintained. It is, of course, necessary to select lamps and resistors with the proper relation in order to maintain a constant instrument supply voltage, and then the voltage can only remain constant within certain limits of input supply voltage.

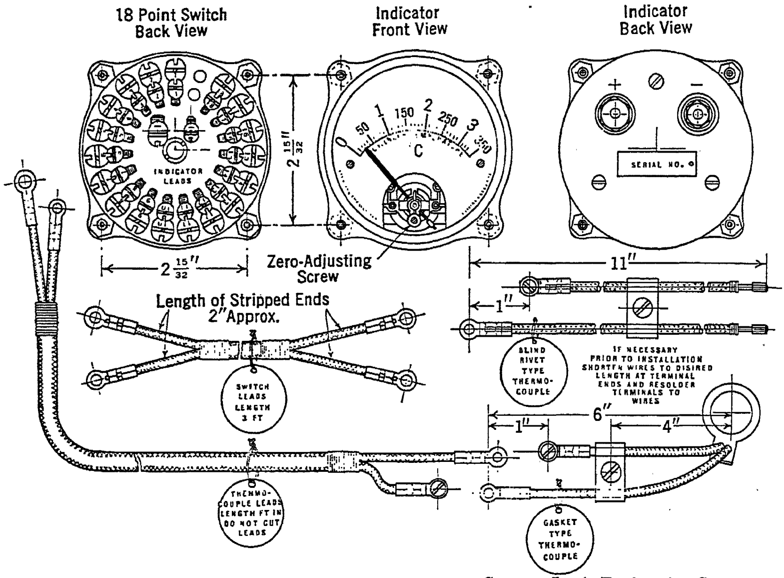
Cylinder Temperature Gauge. The cylinder temperature gauge is used for measuring and indicating temperature at some point on the cylinder or cylinders of an air-cooled engine. The most common point at which the temperature measurement is taken is at the cylinder head, although it is sometimes taken at the cylinder base or other point. Some installations measure the temperatures of several cylinders; in this event it is necessary to have a selector switch if only one indicator is used. The most common practice, though, is to measure the temperature of only one cylinder, selecting that cylinder which will normally run the hottest. The engine manufacturer specifies which cylinder is to be used when the temperature measurement of only one is to be taken.

The cylinder temperature gauge utilizes the thermocouple principle. If two dissimilar metal wires are joined at one end (generally called the hot junction) and the junction is heated, an electromotive force will be generated at the opposite ends of the two wires (generally called the cold junction). The amount of current flow depends upon the difference in temperature between the hot and cold junctions, the type of metals used, and the resistance of the complete circuit.

For measuring cylinder head temperatures the hot junction is a

copper gasket to which the two dissimilar metal wires are brazed or silver-soldered. The gasket, generally referred to as the thermocouple, is installed in place of the conventional spark plug gasket. For measuring temperatures at other points the two wires are joined by silver-soldering in place, adjacent holes usually being drilled to receive the ends of the wires. Thermocouples and lead wires are made of iron and constantan (an alloy of copper and nickel).

The indicator is a sensitive d'Arsonval type of mechanism which measures the flow of current at the cold junction. Since the amount of current flow is dependent upon the difference in temperature between



Courtesy Lewis Engineering Company

FIG. 167. Cylinder temperature gauge with thermocouples, lead wires, and selector switch.

the hot junction (junction at cylinder) and the cold junction (junction at indicator), it is apparent that, in order to indicate the true temperature at the cylinder, some means must be employed to compensate the indicator for the changes in temperature at the cold junction. This is done by means of a bimetallic spiral spring which is connected to the pointer-actuating shaft, the tension of the spring being controlled by the temperature at the indicator.

When installing thermocouples and lead wires it is necessary that similar wires join continuously from the hot to the cold junction. Connections should be clean and tight, as any added resistance caused

by an imperfect contact will result in a false reading at the indicator. Lead wires are constructed with one connecting wire projecting past the other so that normally it is not possible to connect dissimilar wires. Lead wires are commonly made in two sections: one 6-ft lead extending from the thermocouple to the firewall where there is a connecting block, and another lead from the connecting block to the indicator. Leads may be obtained in various lengths to meet the requirements of installation. Each lead is manufactured so that it has a standard resistance, smaller cross-sectional area wire being used in the shorter leads. A lead wire should never be shortened because the circuit resistance would be changed and a false indicator reading would result. The addition of switch lead wires or the shortening of the thermocouple lead-off wires will not materially affect the accuracy of indication, as only a few inches of lead are involved.

To check the zero reading of the indicator, the lead wires are disconnected at the most convenient point or, if a selector switch is used, it is turned to "Off" position. A thermometer is placed in close proximity with the indicator, and sufficient time is allowed for both to indicate the cockpit temperature; then the indicator is adjusted to read cockpit temperature by means of the adjusting screw on the face of the instruments. After adjustment, the lead wire is reconnected.

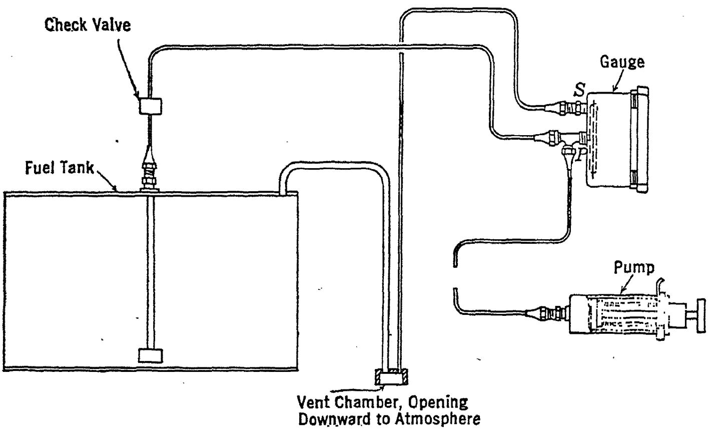
FUEL QUANTITY GAUGES

The purpose of the fuel quantity gauge is to indicate the amount of fuel in the fuel tank or tanks. There are several types of fuel quantity gauges. The majority of them depend upon some type of float mechanism within the tank whose position, owing to the fuel level, actuates an indicator through a mechanical, hydraulic, or electrical mechanism. Some installations are equipped with a glass sight-gauge tube connected directly to the tank, which allows the pilot to see the actual level of fuel in the tank

The hydrostatic type of fuel level gauge operates on the principle that the pressure exerted by a volume of liquid is proportional to its depth. A cell or tube is placed in the fuel tank in an upright position. The bottom of the tube is open and is secured in place very close to the bottom of the tank. (See Fig. 168.) A certain amount of pressure is necessary to maintain the tube full of air, the amount being dependent upon the level of fuel in the tank. The air pressure, obtained by use of a small hand pump, is transmitted through a small tube to the gauge, which is a sensitive pressure indicator, calibrated in gallons or other units of volume. The gauge is somewhat similar in construction to the manifold pressure gauge. Pressure on the inside

of the diaphragm is that required to maintain the column of air in the tank tube. The inside of the case, which is airtight, is vented to the atmosphere. The space in the tank above the fuel level is also vented to the atmosphere. Thereby, the external pressure on the gauge diaphragm is always the same as the air pressure in the upper portion of the fuel tank. The check valve in the line leading to the gauge is to prevent fuel from flowing to the gauge when the airplane is in inverted flight. When in normal level flight the check valve is open.

Changes in altitude and temperature cause expansion and contraction of the air in the hydrostatic fuel gauge system. To make certain



Courtesy United States Gauge Company

FIG. 168. Hydrostatic fuel level gauge installation.

that the system is full of air the pump handle should be pulled out once and released to insure an accurate reading. Small errors are introduced by the change in density of the fuel with changes in temperature. On a hot day the gauge may read less than full when the tank is overflowing, whereas on a cold day it may read full before the tank is filled.

If the hydrostatic pressure gauge installation is correct, errors in indication are due almost entirely to leaks in the system or to fuel or water condensation in the lines. In the event of unsatisfactory operation, the following checks should be made before the gauge is removed from the airplane:

1. *Pressure Line Leak.* Operate the pump and observe the gauge. If an appreciable decrease in reading is observed with lapse of time, test the gauge, line, and pump separately to locate the source. To do this, break the connec-

tion at the tank cell and, holding the end of the tube closed, operate the pump and observe the gauge. (In this test the pump should be operated at about one-quarter of its full stroke.) By breaking each subsequent connection and repeating the operation, the point of leak will be found.

2. *Vent Line Leak.* Seal the vent opening with a hollow rubber stopper fitting with a rubber tube. Suck gently on the tube and pinch off. If the pointer does not hold steady, examine all connections for leaks. After the connections are made tight, if the pointer still drops back faster than 5 deg per min, the leak is probably around the cover glass, and the instrument should be removed for repair.

Leakage tests on both pressure and vent lines must be conducted while the instrument is maintained at substantially constant temperature.

3. *Moisture in Lines.* If the presence of fuel or water in the lines is suspected, the lines should be disconnected at the gauge and at the tank and blown out from the gauge end with dry compressed air at a moderate pressure for a sufficient time for the fuel or water to evaporate.

4. *Fuel or Moisture in Capillary Damping Tube.* The presence of fuel or moisture will be revealed by excessive sluggishness of the indicating pointer. The capillary is located in the end of the tee that is screwed into the case. Remove the tee and run a piece of 0.005-diam steel wire in the bore of the capillary tube to dislodge any foreign matter therefrom. Allow it to dry thoroughly before replacing. Blowing through with clean dry air will assist in drying.

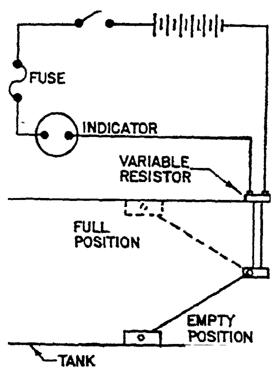


FIG. 169. A simple electrical fuel quantity gauge installation.

There are numerous forms of electrically operated fuel level gauges, some of which employ a d'Arsonval mechanism in the indicator in conjunction with a rheostat operated by the float mechanism. The wiring diagram of an installation using the ratio meter type of indicator, described on page 213, is illustrated in Fig. 170. The tank unit float mechanism operates a potentiometer which controls the amount of current flowing through each of the two coils of the ratio meter indicator. The accuracy of the reading of such an installation is not affected by slight fluctuations in supply voltage.

Where several fuel tanks are employed in one airplane it is possible to use one electrical indicator and a selector switch for all of the tanks. Any difference in the size or shape of the tanks necessitates a separate calibration on the indicator dial for each type of tank. Variable resistors are incorporated in the electrical circuit so that the full and empty adjustment settings may be made for each tank.

The maintenance of fuel quantity gauges will be dependent upon the type of gauge installed, although it may be said that the general routine maintenance for instruments is sufficient except in the event

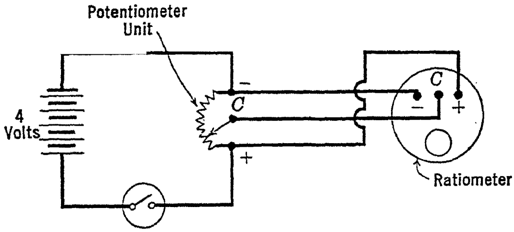


Fig. 170. Wiring diagram of the ratio meter fuel level gauge.

of malfunctioning. The full and empty readings should be checked at periodic inspections. The readings may either be checked while the tank is empty and then while it is full or, if it is not desirable to fill the tank, the float mechanism, on installations using such, may be held in their highest position by hand. However, checking by raising the float by hand will not reveal the deficiency of a float which has lost some of its buoyancy.

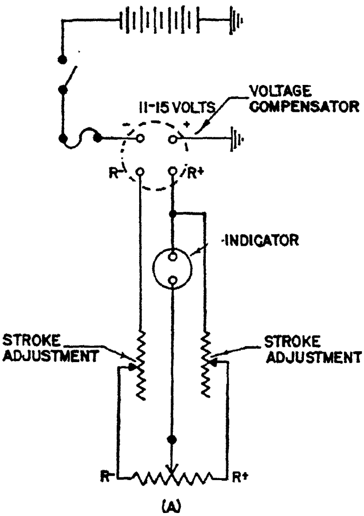
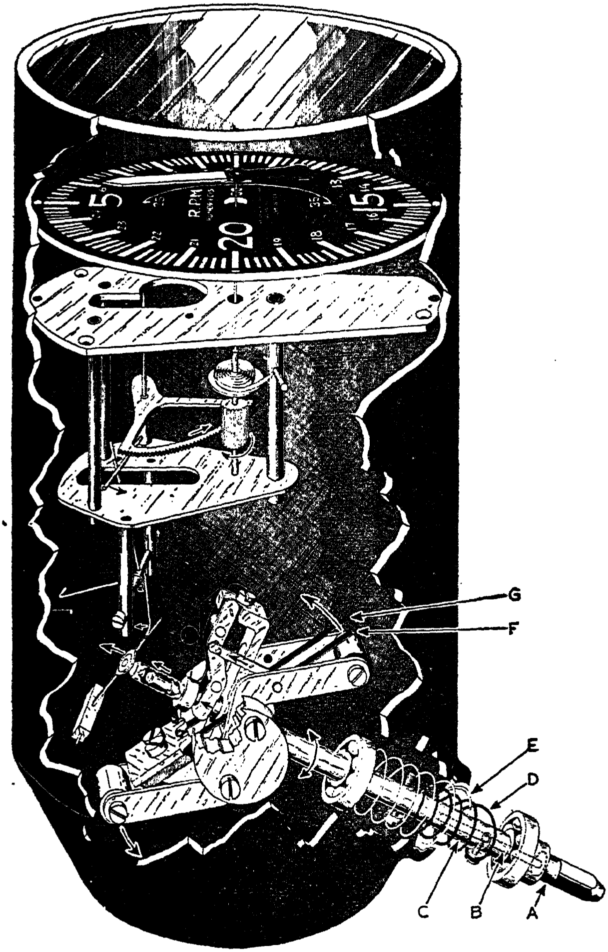


Fig. 171. Wiring diagram of Liquidometer type of fuel and oil quantity electric gauge.

TACHOMETERS

Centrifugal Tachometer. The purpose of the tachometer is to measure the engine crankshaft revolutions per minute (rpm). The centrifugal tachometer operates on the same principle as the often used flyball governor. As the speed of the governor increases the centrifugal force increases, causing the flyballs to stand out farther from the axis of rotation. In the tachometer the force restraining the outward movement of the flyweights is a spring, rather than gravity. The position of the tachometer flyweights, which is determined by their revolutions per minute, is transmitted through a series of levers, pinions, and gear segments to the pointer which indicates on a

dial graduated in revolutions per minute, as may be seen in Fig. 172. The flyweights are connected through a flexible shaft to a drive at the engine.

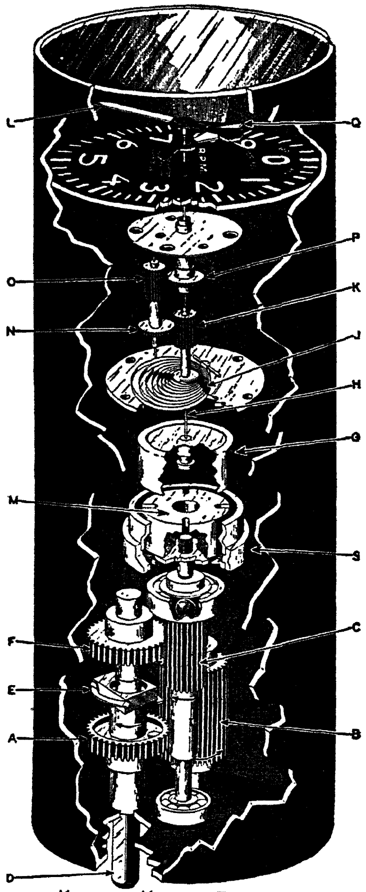


Courtesy Kollsman Instrument

FIG. 172. Illustrative drawing of a centrifugal tachometer.

Magnetic Tachometer. In the magnetic tachometer the speed is measured by turning a magnet *M* inside a cup or drum *G* of special metal (see Fig. 173). The drum is pulled around by the magnet against the force of a hairspring *J*. The balance of force between the pull of the magnet and that of the spring makes the drum take up a

position which is a measure of the speed. One or more pointer hands are turned by the turning of the drum, giving the speed reading on the dial. The gear mechanism shown below the magnet M is so arranged with clutches that the magnet will always turn in the same direction regardless of the direction in which the shaft D is rotated.



KOLLSMAN MAGNETIC TACHOMETER

Courtesy Kollsman Instrument

FIG. 173. Illustrative drawing of magnetic tachometer.

Electric Tachometers. On multiengine installations and installations where it is desirable to locate tachometer indicators at more than one point, the installation of tachometer driveshafts becomes both cumbersome and an item of weight consideration. To alleviate these undesirable features the electric tachometer is employed.

There are several types of electric tachometers. The generator-voltmeter type of tachometer consists merely of a d-c generator driven by the engine, a set of lead wires, and an indicator which is virtually a voltmeter calibrated in revolutions per minute. The output voltage of the generator is directly proportional to its speed, hence, by calibrating the voltmeter in revolutions per minute rather than volts, the engine speed may be read directly from the indicator. The generator may be driven in either direction of rotation, it being necessary only to shift the leads when changing rotation to allow the indicator to read correctly. Installation may be made with one or two indicators operating from one generator. The wiring diagrams of both single and double installations are shown in Fig. 174.

A later model of the generator-voltmeter tachometer employs an a-c generator rather than a d-c generator. With the a-c generator no commutators or brushes are necessary. These are a source of trouble

in the d-c generator. Before the alternating current goes into the voltmeter it passes through a rectifier, located at the indicator, where it is rectified to direct current.

Another type of electric tachometer employs the magnetic tachometer indicating mechanism, as previously described, but instead of the magnetic mechanism being driven by a driveshaft running from the engine, it is driven by a synchronous motor, which itself is driven by a 3-phase alternator at the engine. The synchronous motor at the indicator always turns at the same speed as the alternator at the engine.

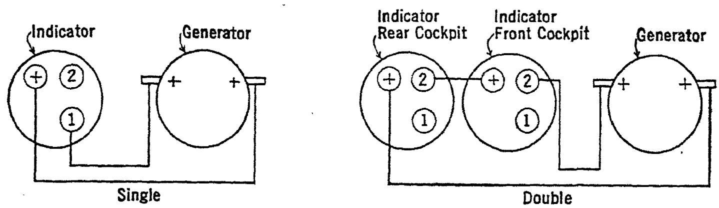


FIG. 174. Wiring diagram of generator-voltmeter tachometer installation.

A 3-wire lead from the alternator to the motor is the only connection necessary. Terminals of like markings at the alternator and motor must be connected to the same wire.

Maintenance. Tachometer shafts should be installed so that all bends are in as large a radius as possible. Shafts are furnished packed with lubricant. If replacement of lubricant becomes necessary a light coat of high grade vaseline may be used.

The electrical connections of electric tachometers should be checked at regular intervals to make sure that they are clean and secure. There is considerable vibration at the engine unit; this tends to loosen the connections.

On multiengine installations the accuracy of one tachometer may be checked against another where an engine synchronizer is installed.

The tachometer drive coupling on all standard American engines turns at one-half crankshaft speed. Therefore, when bench-testing a tachometer the indicator should read twice the actual speed at which the tachometer is being driven.

ENGINE SYNCHRONISM INDICATORS

On multiengine aircraft it is desirable to adjust all engines to the same speed after the cruising attitude has been assumed. The tachometers may be used for adjusting all engines to approximately the

same speed, but for fine adjustment a more accurate indication is necessary.

Engine Synchronism Indicator — Weston Type. This type of indicator is used in conjunction with the generator-voltmeter type electric tachometer. It consists of a sensitive high resistance millivoltmeter which measures the difference in voltage generated by two tachometer generators. The indicator scale is marked zero in the center and graduated to a range of 50 rpm on either side of the zero. A greater voltage output at one of the tachometer generators, caused by a greater speed, will cause the indicator hand to deflect in one direction. A greater voltage output by the other generator will cause it to deflect in the other direction. Accuracy is within 2 rpm.

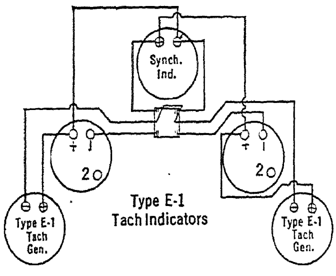


Fig. 175. Wiring diagram for installation of generator-voltmeter tachometers and synchronism indicators.

An installation wiring diagram of the indicator is shown in Fig. 175. A double-pole double-throw switch is provided to give a selection for tachometer operation or synchronizer operation. It is not possible to operate the tachometer indicators and synchronizer indicator simultaneously. Before installation it is necessary to bench-test both tachometer generators with the synchronizer to make certain that both generators are producing exactly the same voltage at similar speeds. First, the synchronizer pointer is adjusted to zero by means of the screw on the face of the instrument. While both generators are running at 1800 rpm on the test stand, the synchronizer should read zero. If it is off center, remove the adjusting screw cap from one of the generators and adjust until the reading is zero. If the indicator is more than 10 rpm off center, half the adjustment should be made on each generator. The error in indicator reading at any speed other than 1800 rpm should not exceed 2 rpm.

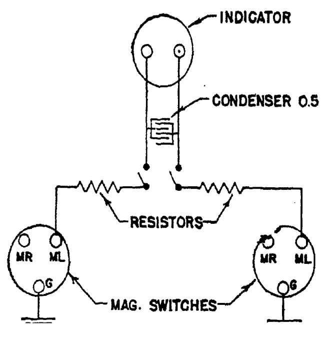
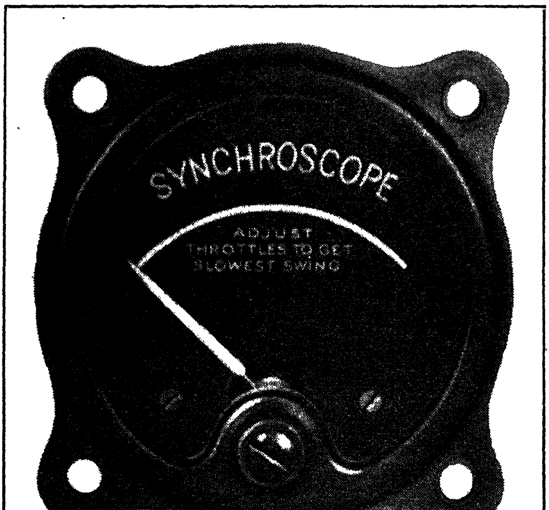


Fig. 176. Wiring diagram of two-engine synchroscope installation.

Eclipse Engine Synchroscope. This type of engine synchronizer indicator consists of a voltmeter which measures the effective voltage of two alternating currents. The source of the alternating current is the engine magneto primary circuit whose frequency is dependent upon the engine speed. The indicator is connected to the primary circuit of one magneto on each engine. Connection is made at the magneto switch as shown in the wiring diagram of Fig. 176. Two single-pole single-throw switches are used to turn the synchroscope on and off.

The combined effective voltage of two alternating currents of different frequencies is constantly rising and falling. The rate at which the rise and fall occurs is dependent upon the difference in frequencies of the two currents. If the a-c frequencies are the same the combined effective voltage remains constant, its magnitude being dependent



Courtesy Eclipse Aviation

FIG. 177. Dial face of the synchroscope.

upon the phase relation of the two currents. The synchroscope utilizes the above facts. When both engines are running at exactly the same speed the synchroscope pointer remains stationary. Its position is immaterial as long as it remains stationary. A change of the speed of one engine will result in a difference in frequency of the alternating currents. This will result in a rising and falling of the effective voltage which causes the synchroscope pointer to swing back and forth; the fre-

quency of swing is dependent upon the difference in speed of the two engines, a larger difference causing a more frequent swing.

The effective voltage produced by various magnetos is not the same. So that the same indicator may be used with all types of magnetos, resistors are placed in the line from the magneto to the synchroscope. A set of resistors should be used which will give the instrument a deflection of approximately half scale when the two engines are running at speeds 300 rpm apart.

When the synchroscope is not in operation, the pointer should stand at the left end of the scale. Adjustment may be made by means of an adjusting screw in the cover glass.

Care must be taken to prevent possibility of grounding of wires leading from the magneto switches to the synchroscope. A ground in any part of the synchroscope circuit will cause one or both magnetos to cut out.

REMOTE INDICATING INSTRUMENTS

Remote indicating instruments provide a means of measuring engine functions at or close to the engine and transmitting the measurements electrically to the cockpit instrument panel. Such a system is especially desirable on multiengine aircraft as it eliminates long tubing and driveshafts, errors in oil pressure indication due to oil congealing in the gauge line at low temperature, and fuel and oil lines to the pilot's compartment (thereby reducing the fire hazard), and conserves instrument board space by using dual- and multiple-scale indicators.

Remote indicating instruments are manufactured under several trade names such as Autosyn, Telegon, and Selsyn. The transmission is based upon the principle of self-synchronous motor operation. Engine instruments, exactly like the conventional instruments which have been described throughout this chapter, are mounted on a panel close to the engine and connected up in the regular manner. The pointers of the instruments, instead of indicating on a dial, are connected to a "transmitter." Any movement of the instrument pointer causes a movement of the transmitter rotor which, in turn, causes a movement of the indicating pointer on the "receiver" in the cockpit.

The transmitting and receiving elements are alike in construction except for their cases. The transmitter case is constructed to allow attachment of the measuring instrument. The receiver is provided with a dial face and indicating pointer. Some receivers are built in tandem, that is, with one receiving unit behind the other and both having pointers which indicate on the same common dial.

A wiring diagram of the transmitter and indicator is shown in Fig. 178. The three stationary windings of both units are connected in parallel. The field windings of the rotors of both units are connected in parallel across an a-c supply line. A-c supply is usually furnished by an engine-driven alternator or electrically driven dynamotor. When the a-c supply is turned on the rotor field windings set up an alternating magnetic field. The magnetic field at one instant is indicated by the arrows in Fig. 178. The alternating fields induce a volt-

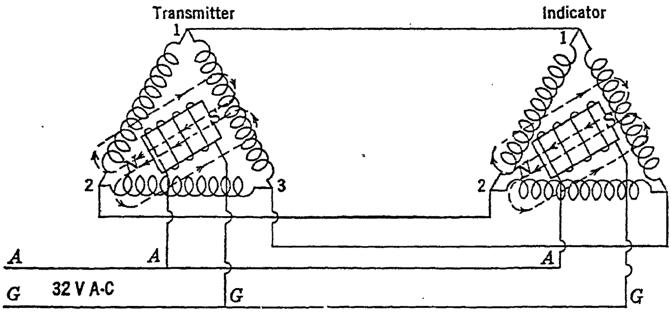


FIG. 178. Wiring diagram of self-synchronous remote indicating instruments.

age in the three stator windings of both transmitter and receiver. The amount of voltage induced in each stator winding is dependent upon the angular relation with the rotor field winding. If the angular relation of the rotor field windings with the stator windings is not the same at both transmitter and receiver, the same voltage will not be induced in similar stators at the transmitter and the receiver. If the voltages induced in the stators are not the same there will be a current flow in the stator windings and between the stators of the transmitter and receiver, since they are connected in parallel. This flow of current will cause the rotors to move to like positions, in which there will be no flow of current between stators because there will be no difference in voltages. Any subsequent movement of one of the rotors will be followed by a similar movement of the other rotor to maintain the same voltage in similar stator windings. In this manner the gauge pointer, which in normal installations indicates on a dial, is connected with the rotor of the transmitter and, by moving the transmitter rotor, the measurement is transferred to the receiver pointer in the cockpit.

Remote indicating instruments require no special maintenance procedure. The maintenance required for the individual measuring units as outlined throughout this chapter are applicable. Before an instrument is removed for malfunctioning the current supply and continuity

of electrical wiring should be checked. Like terminals at both transmitter and receiver must be connected to the same wire. The continuity of wiring may be checked by a battery and lamp circuit. The internal wiring of transmitters and receivers may be checked by an ohmmeter. The manufacturer will specify the correct internal resistance of the stators and rotors, which will be approximately 50 ohms for each.

FUEL-AIR MIXTURE RATIO INDICATOR

On engines with fixed pitch propellers a method of mixture control may be used which takes advantage of the fact that the engine rpm drops as the mixture is leaned or enriched beyond certain fuel-air ratios. On engines equipped with constant speed propellers this method cannot be used since the rpm remains constant even when the mixture is lean enough to damage the engine or rich enough to cause excessive fuel consumption. It therefore becomes necessary to have some positive method of measuring the fuel-air mixture ratio so that manually controlled mixtures may be set correctly on installations with constant speed propellers.

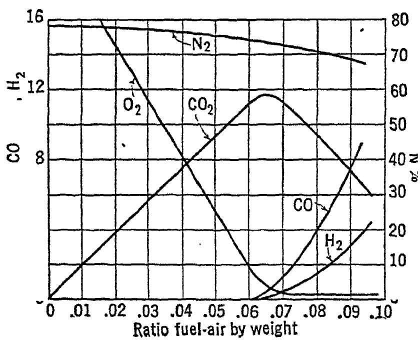


FIG. 179. Curves showing change in exhaust gas composition with change in fuel-air mixture ratio.

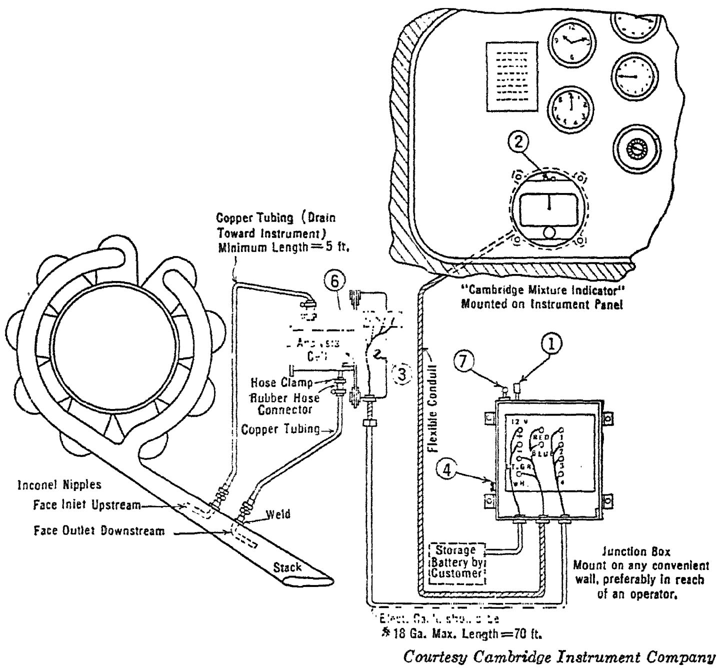
The fuel-air mixture ratio indicator takes advantage of the fact that the composition of the exhaust gases varies as the mixture ratio varies. Samples of the exhaust gases are analyzed and from this analysis the fuel-air mixture ratio entering the cylinders is determined.

The engine exhaust is composed of several gases, including carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), hydrogen (H_2), and nitrogen (N_2). The proportion of these gases in the exhaust is definite and varies with the fuel-air mixture ratio supplied to the cylinders, as may be seen from the curves in Fig. 179. Hence, an instrument which will respond to changes in the proportion of certain of the exhaust gases can readily be used to indicate the ratio of the fuel-air mixture.

Inspection of the curves of Fig. 179 shows that as the mixture is enriched there is an increase of H_2 in the exhaust and a decrease in the

CO_2. The thermal conductivity of H_2 is about six times that of air, and that of CO_2 is about one-half that of air. The principle of operation of the instrument is based upon this difference in the thermal conductivity of two gases whose proportions vary with changes in fuel-air ratio. Although the proportion of the N_2, CO, and O_2 also varies, their thermal conductivity is considered as about equal to that of air as far as the operation of the instrument is concerned.

A typical fuel-air mixture indicator single-engine installation is illustrated in Fig. 180. An inlet and outlet nipple in the exhaust stack



Courtesy Cambridge Instrument Company

FIG. 180. Typical single-engine fuel-air mixture ratio indicator installation.

provide a continuous sample stream of exhaust gases to the analysis cell. The analysis cell is composed of four platinum spiral resistors forming the four arms of a Wheatstone bridge, as may be seen in the wiring diagram of Fig. 181. When all four resistors are at the same temperature the bridge is electrically balanced. The two resistors *B* and *B* are exposed to the sample exhaust gases. The two resistors *A* and *A* are sealed in a chamber exposed to moisture-saturated air, which is called the " standard " gas.

The current supply to the instrument goes through a ballast tube where it is reduced to 4.1 volts. The ballast tube is a resistor sealed in a hydrogen-filled glass bulb. Slight fluctuations in supply voltage are reduced to such small proportions by the ballast tube as to be negligible. The current supply to the four resistors of the Wheatstone bridge stabilizes their temperature at 260°F. As the exhaust gases flow around the two exposed resistors, *B* and *B*, they will be cooled. The amount of cooling will depend upon the proportion of H_2 and CO_2 in the exhaust gases. The greater the proportion of H_2, the greater will be the amount of cooling.

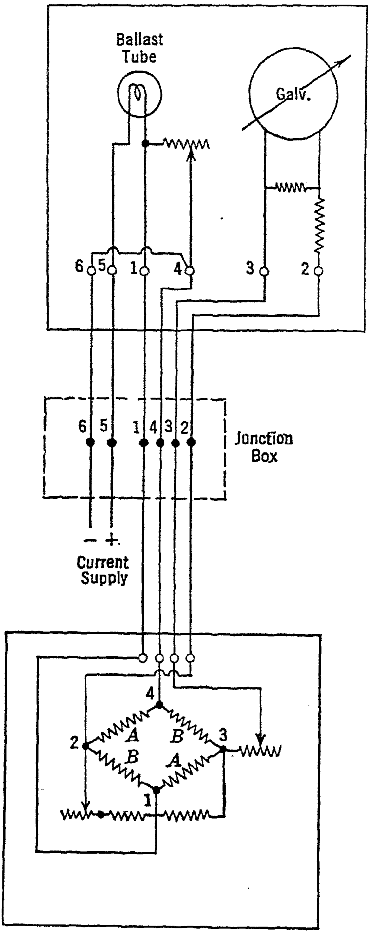
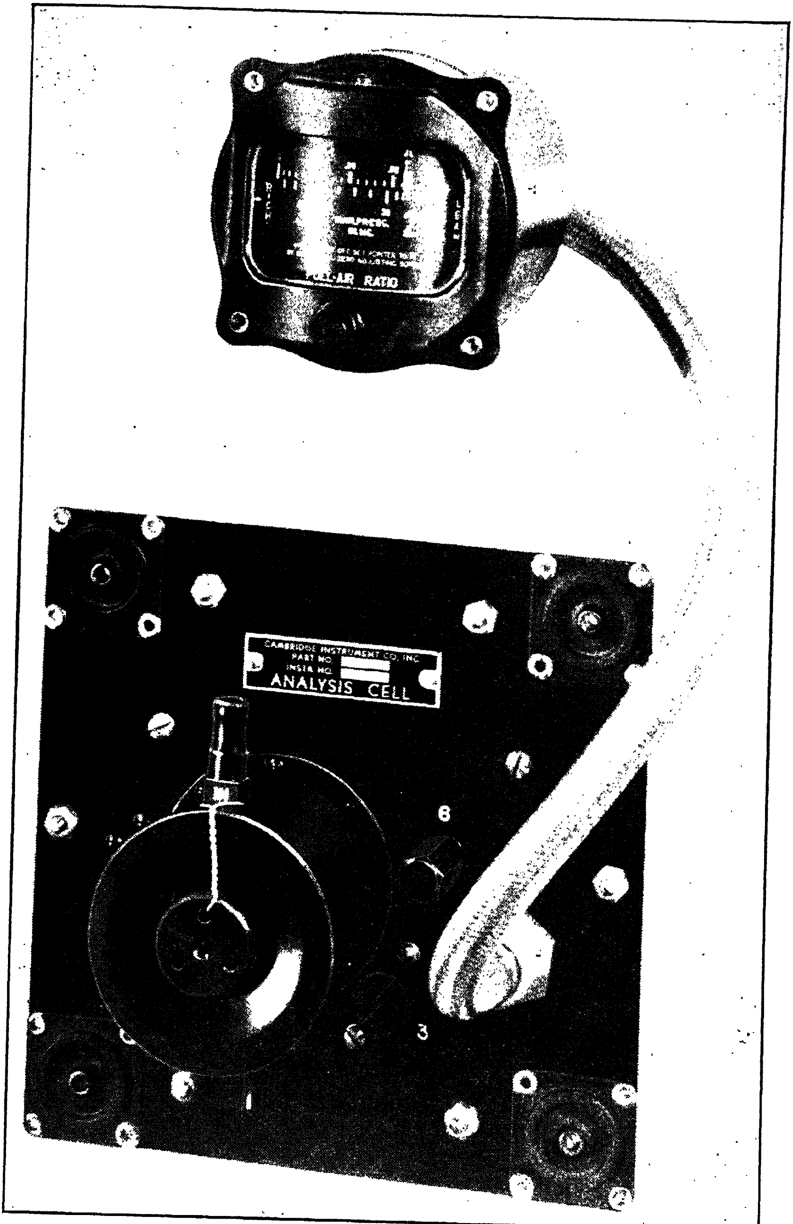


Fig. 181. Wiring diagram of single-engine fuel-air mixture ratio indicator installation.

As the resistors *B* and *B* are cooled their resistance is lessened; this causes the indicator needle to move toward the rich side. The movement of the indicator needle is in direct proportion to the increase in H_2 gas. As the proportion of H_2 decreases and CO_2 increases heat is carried off less rapidly from the resistors. The increase in temperature of the two resistors *B* and *B* results in an increase in resistance which causes the indicator needle to deflect toward the lean side. The temperature and hence the resistance of the two resistors *A* and *A* always remains constant since they are always exposed to the "standard" moisture-saturated air.

There is one exception to the normal operation of the fuel-air mixture ratio indicator. If the mixture is leaned to the point where detonation occurs, the amount of H_2 present in the exhaust does not follow the curve of Fig. 179 but increases rapidly. This increase in H_2 will cause the indicator needle to swing to the rich side although the mixture is excessively lean. This charac-



Courtesy Cambridge Instrument Company

182. Indicator and analysis cell of the Cambridge fuel-air ratio indicator.

teristic may be used as a warning of detonation. Slight detonation will cause fluctuations of the pointer.

In addition to the general instrument maintenance outlined in this chapter, the instrument manufacturer recommends that the following service operations be performed at periods corresponding to approximately 100 flying hours.

1. The sampling nipples and gas line should be cleaned out and joints tightened where necessary. A drill of the proper size welded to the end of a length of tachometer shaft forms a good clean-out tool, or the gas line may be removed from the plane and the carbon deposit burnt out with a blowtorch; this will also serve to anneal the line.

2. Renew rubber shock mounts of the analysis cell where necessary.

3. Remove filter wool and wash with gasoline or replace with new wool if necessary. Also clean out filter chamber.

4. Test the indicator unit for pointer stiction by noting the pointer position with the current off. Then turn the current on to cause a movement of the pointer (it may be necessary that there be exhaust gas in the cell to cause this movement), and then off again. The pointer should return to its original position. If it does not and the indicated stiction is greater than 0.002 fuel-air ratio, the unit should be repaired at the earliest opportunity.

5. Wet the wick in the vapor plug (No. 6, Fig. 180), make sure the breather hole (size 80 drill) in the plug is open, and replace.

6. *Mechanical Zero Adjustment.* With the current off, the pointer should stand at *A* on the scale. If it does not, adjust to this position by means of the zero screw on the indicator front.

7. *Electrical Zero Adjustment.* The position of the pointer on the electrical zero is the same as on the mechanical zero.

To check:

a. First see that the mechanical zero is properly set.

b. Wet the wick in the vapor plug (No. 6, Fig. 180) of the analysis cell.

c. Remove cover and steel wool from filter chamber of the analysis cell, allowing time for any residual gas to be displaced by fresh air. Then place inside this chamber a clean, wet rag that has been slightly wrung out, and replace the cover.

d. Now, with the current on, allow the instrument to stand thus for about 30 min; at the end of this time the pointer should stand at *A* on the scale. If it does not, adjust to this position by means of rheostat (No. 3, Fig. 180) in the analysis cell. The wet rag should then be removed from the filter chamber and the steel wool and cover replaced. When replacing the wool, push in sufficiently to clear the opening of the inlet pipe.

CHAPTER IX

ACCESSORIES

The primary accessories, necessary to the functioning of the engine, are covered under appropriate headings throughout this book. Only the secondary accessories, without which the engine could still operate, will be discussed in this chapter.

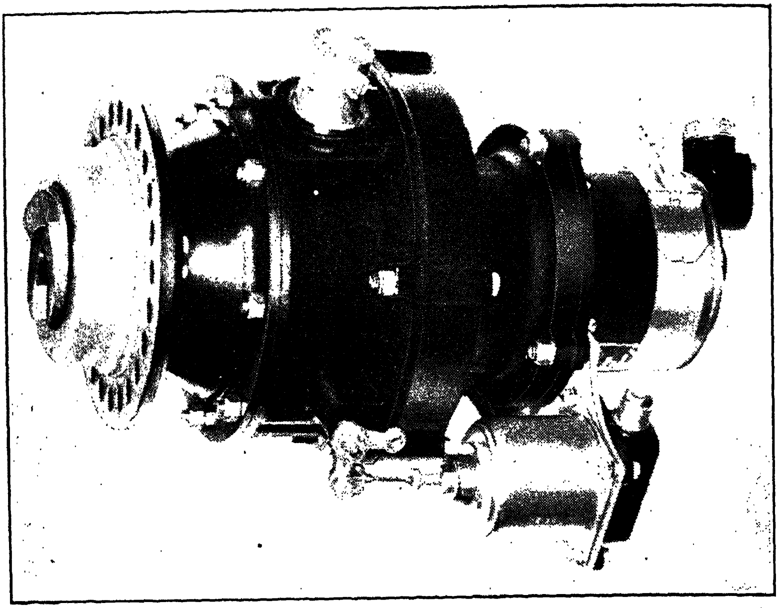
In general the overhaul period of the secondary accessories coincides with that of the engine. A relatively small amount of maintenance is required between overhauls. However, there are many types and many manufacturers of the various accessories and the service instructions covering each particular accessory in use should be consulted.

STARTERS

Many of the low powered engines are started by pulling the propeller through by hand. On the higher powered engines this procedure is not feasible and some type of mechanical starter must be resorted to. A choice of several types of starters is available.

The *inertia starter* depends upon the energy stored in a rotating flywheel for turning over the engine. The flywheel is brought up to a speed of approximately 12,000 rpm by either a manually operated crank or by an electric motor. After the flywheel is energized the starter jaw, which is geared to the flywheel, is meshed with the engine jaw. The meshing device may be operated by a manual control or an electric solenoid. The meshing control may also operate a booster coil switch. A protective clutch is incorporated in the driving mechanism of the starter. The purpose of this clutch is to protect the starter during backfire of the engine or other excessive loads.

Upon starting, the engine jaw automatically disengages from the starter jaw. If the starter is allowed to run down while engaged without the engine starting, it will be necessary to rotate the engine about ½ revolution in its normal direction of rotation before the jaws disengage. There should be no attempt to energize the starter until the jaws have been disengaged. Before the engine is turned to disengage the jaws, the aircraft main battery switch should be turned "off." If this is not done the booster coil will remain energized on installations

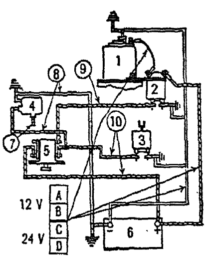


Courtesy Eclipse Aviation

FIG. 183. Combination hand and electric inertia starter with integral solenoid meshing device.

1. Starter Motor
2. Solenoid Starting Switch
3. Solenoid Meshing Device
4. Booster Coil
5. Double-Contact Push-Pull Switch
6. Battery
7. To Distributor
8. No. 16 Camb. Insul. Cable
9. No. 14 Cambric Insul. Cable
10. No. 10 Cambric Insul. Cable

Note: For one-wire grounded systems use sectioned lines only. For two-wire ungrounded systems disconnect all ground wires and use full lines in addition to sectioned lines.



Caution

Motors fitted with one terminal post are grounded internally.

Motors fitted with two terminals may be converted to one-wire grounded systems by replacing the insulating washer on either terminal post with a steel grounding washer.

Two-wire solenoid switches and meshing devices may be converted to one-wire grounded systems by replacing either terminal insulating bushing with a grounding bushing.

Mount all booster coils on a grounding base as the secondary winding is grounded internally for both one- and two-wire systems.

To convert one-wire grounded booster coil for two-wire ungrounded operation remove the grounding washers and insulate the primary terminal post.

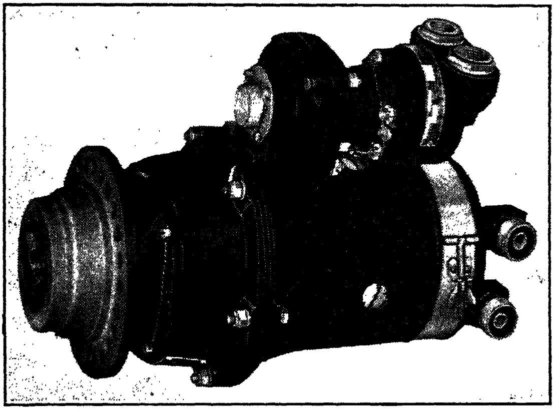
Courtesy Eclipse Aviation

FIG. 184. Wiring diagram for electric inertia starter complete with booster coil, solenoid starting switch, solenoid meshing device, and double-contact push-pull switch.

which control the booster switch with the meshing device, with the resultant danger of the engine firing while being turned by hand.

The *direct-cranking electric starter* consists basically of an electric motor, a reduction gear, a protective clutch, and an automatic engaging and disengaging mechanism. The electric motor is series wound, that is, the field winding is connected in series with the armature. In such a motor the field current increases with load and provides a maximum torque for starting.

Some direct-cranking electric starters incorporate a hydraulic gear-type pump for use in the feathering and unfeathering of Hydromatic propellers. When used as a starter the operation is the same as any other direct-cranking starter. When used to operate the hydraulic pump the starter armature rotates in the direction opposite from nor-



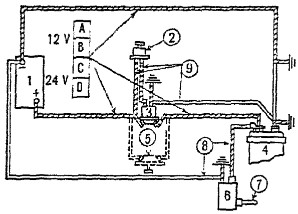
Courtesy Eclipse Aviation

Fig. 185. Direct-cranking electric starter with integral hydraulic pump for propeller feathering.

mal rotation, engaging the pump driving gears through a mechanism similar to the "free wheeling" device used on some automobiles. To provide armature rotation in either direction it is necessary to have two field windings, the direction of rotation depending upon which field the current is directed through.

Electric starters are lubricated at overhaul and do not require any lubrication between overhauls. The functioning of the starter is, of course, tested each time the engine is started. At periods of approximately 200 flying hours the window strap should be removed for inspection and cleaning as prescribed for generators (page 241).

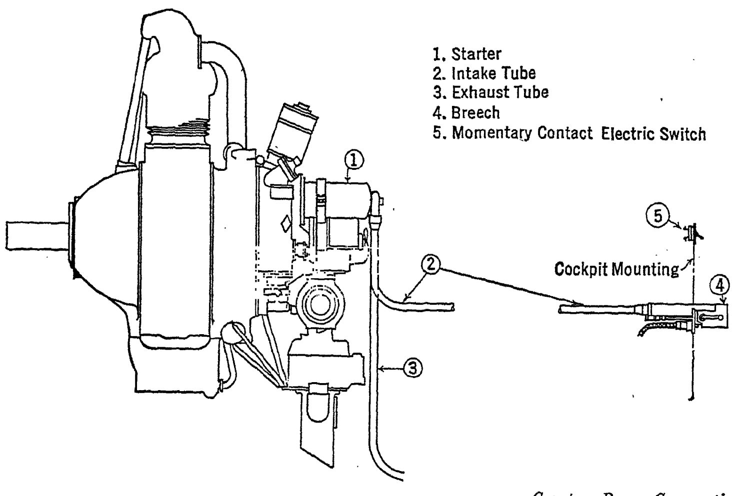
The failure of a starter to develop sufficient torque for starting the engine is an indication that the clutch is slipping owing to worn or



Courtesy Eclipse Aviation

FIG. 186. Wiring diagram for direct electric starter complete with booster coil, solenoid starting switch and push switch showing one- and two-wire systems.

scored discs or leakage of engine oil into the starter interior, as a result of worn oil seal. Leakage of oil into the starter gear case and



Courtesy Breeze Corporation

FIG. 187. Installation diagram of a cartridge starter.

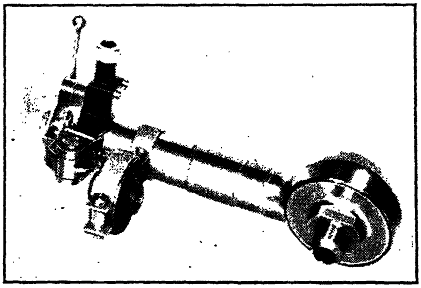
around the flywheel of inertia starters will make it impossible to energize the flywheel. If such troubles are experienced with starters, they should be removed for overhaul.

The *cartridge starter* utilizes the energy released by the explosion of a relatively slow-burning powder contained in a cartridge for the starting of the engine. The gases released by the explosion of the cartridge are conveyed from the breech through a tube to the starter. The gases enter the starter cylinder and force the piston within the cylinder forward. The longitudinal movement of the piston is transformed into rotary motion by a screw shaft arrangement, thereby imparting torque to the engine. When the piston has moved a certain distance of its stroke, it opens an exhaust valve which permits the gases to exhaust to the atmosphere. The piston, thus relieved of the gas pressure, returns to its original position as a result of the action of a heavy helical spring, thereby closing the exhaust valve and, at the same time, retracting the starter jaw. A safety relief valve is provided to prevent excessive pressures which might be built up in the cylinder and tubing.

At periods of approximately 50 hr of flying time or after about 50 cartridges have been fired, whichever occurs first, the breech bore should be cleaned with a cotton swab attached to a cleaning rod. The cleaning solution should consist of the following:

25% Benzine (62° Baumé)
25% Turpentine
25% Amyl acetate
12½% Acetone
12½% Lubricating oil (S.A.E. 30)

The two drilled passage holes in the breech should be cleaned with a stiff wire. The breech should be washed thoroughly with kerosene or clear gasoline after cleaning. All external moving parts should be lubricated with light machine oil except the locking lug, which may be lubricated with white lead. All tubing and connections should be examined for signs of leakage.



Courtesy Eclipse Aviation

FIG. 188. Cartridge starter breech mechanism.

At periods of approximately 100 hr of flying time, or after 100 cartridges have been fired, the breech mechanism should be disassembled sufficiently for thorough cleaning with the above cleaning solution. All parts should be washed with clear gasoline and lubricated

after cleaning. The relief valve ball seat should be resurfaced by lapping if necessary. All electrical contacts should be cleaned with No. 000 sandpaper. After reassembly the electrical circuit continuity should be tested with a battery and lamp.

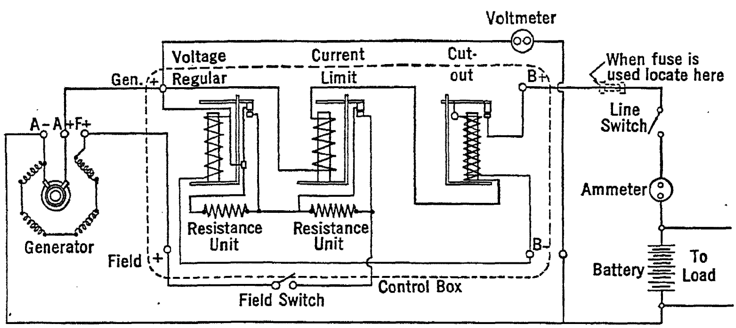
Further instructions concerning the operation of the cartridge starter will be found in Chapter XIII.

GENERATORS AND CONTROL BOXES

The typical battery charging system consists of an engine-driven generator, a cut-out switch, a voltage regulator, and a current limitator. The latter three units are all contained in one assembly called the generator control box. A schematic wiring diagram of the complete system is shown in Fig. 189. The majority of aircraft use a 12-volt battery system, although some of the larger aircraft are now using 24 volts and higher.

The generator is a plain shunt-wound type. A flexible coupling is located between the splined driving shaft and the armature to absorb any torsional vibration or other excess torsional loads.

Through the use of the *voltage regulator* the generator operates as a constant voltage machine. After the generator attains a speed suffi-



Courtesy Eclipse Aviation

FIG. 189. Schematic wiring diagram of generator and control box.

cient to generate 14½ volts, any further increase in speed does not increase the voltage output. The wiring diagram will show that the core winding of the voltage regulator is connected across the output terminals $A(+)$ and $A(-)$ of the generator. When the generator voltage exceeds 14½ volts, sufficient current passes through the voltage regulator core to open the contact points, thus throwing a fixed resistance into series with the generator field winding. This reduces the generator voltage output. As the voltage drops below 14½ volts

the contacts close, taking the resistance out of the field winding circuit. This cycle of cutting the field resistance in and out is repeated at rapid intervals and maintains the generator voltage constant at all speeds above the critical speed, at which it develops the normal voltage with the resistance cut out of the field circuit. The actual voltage is a series of very fine ripples, above and below the normal constant voltage for which the regulator is set. The regulator spring tension should never be increased in an attempt to have the generator charge at a higher rate at low speed. The generator does not begin to charge until the cut-out closes, and its action is independent of the regulator.

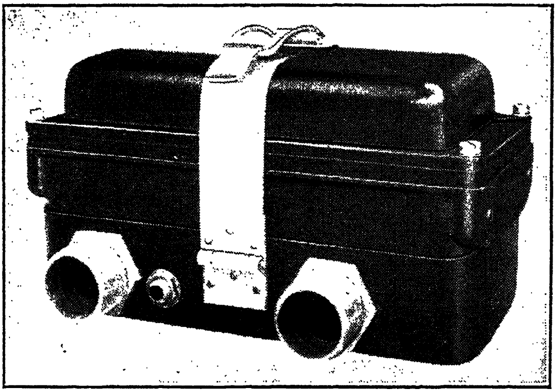
The *cut-out* is a device for opening and closing the electrical connection between the generator and the storage battery. Such a device is necessary to prevent a discharge of current from the battery through the generator when the generator is idle or operating at low speeds. The cut-out core consists of two windings. One, consisting of many turns of fine wire, is connected across the output terminals $A(+)$ and $A(-)$ of the generator. The other, consisting of a few turns of comparatively heavy wire, is connected in series with the $A(+)$ side of the generator-battery circuit.

The spring tension on the cut-out contact points is set so that they remain open until the generator is running at a speed sufficient to develop a voltage of 13½ volts across the fine wire shunt winding of the cut-out core. When the contact points close, the circuit between the generator and battery is closed. When the generator and battery circuit are closed a current flows in the heavy wire series winding of the cut-out core which reinforces the pull of the fine wire shunt winding, and firmly holds the cut-out contacts in the closed position. When the speed of the generator is decreased until its voltage output is below that of the battery, a momentary discharge of the battery through the series core winding takes place. When the flow of current in the series core winding is reversed, the magnetic pull of the series coil acts against the pull of the shunt coil. When the total magnetic pull is decreased the spring tension on the contact points is sufficient to open them.

The *current limitator* has one core winding of relatively heavy wire which is connected in series with the $A(+)$ side of the generator-battery circuit. As the current passing through the core coil increases, the magnetic pull against the contact point armature increases. When the current reaches the value for which the contact point spring tension has been adjusted the contact points open, thus breaking the generator-to-battery circuit. The purpose of the current limitator is to limit the current output to the rated capacity of the generator.

Otherwise, the generator might become overtaxed and cause overheating and possibly other injury.

Since the generator output voltage remains constant the amount of current generated will depend upon the charge of the battery and the amount of load in use. Although a 6-cell storage battery is referred to as a 12-volt battery, the voltage across the terminals is actually approximately 14½ volts when the battery is fully charged. There-



Courtesy Eclipse Aviation

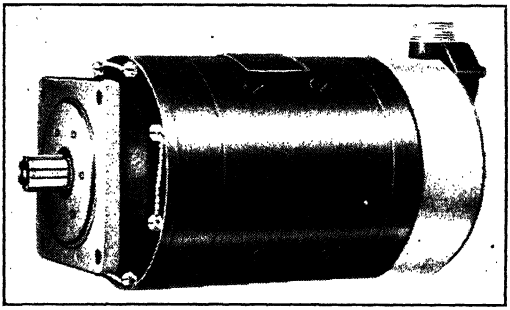
FIG. 190. Three-unit detachable-type control box.

fore, if the battery is fully charged and the generator is producing 14½ volts, there will be no current flow from the generator to the battery, since both their voltages are the same. In such a case it will appear that the generator is not functioning, since the ammeter in the generator-battery circuit will not show any indication. To ascertain whether or not the generator is functioning properly, a load is applied to the circuit, such as a load imposed by turning on the landing lights, and the ammeter will immediately indicate a current flow if the generator is functioning.

The control box should be mounted at some convenient place on the aircraft where it will receive a minimum amount of vibration. It is preferable to shock-mount the unit so that vibration from the aircraft will have the minimum effect upon the operation of the voltage regulator. At periods of approximately 100 hr of flying time the control box cover should be removed and the voltage regulator contacts inspected. Before attempting to inspect or service either the control box or the generator in the airplane, one should make sure that the battery master switch is open or that both battery terminals are removed. Dirt may be removed from the points by pulling a piece of

paper between them as they are pressed together. If the contacts are burned or pitted they may be dressed off with a small ignition contact file or crocus cloth and then cleaned with the paper. It is imperative that the interior of the box be kept clean to prevent dirt from collecting on the contacts.

The generator window strap should be removed and an inspection made for dirty or loose connections and worn or binding brushes. Binding brushes should be wiped clean with a cloth moistened with clear unleaded gasoline. Dirty commutators may be cleaned with a



Courtesy Eclipse Aviation

FIG. 191. Engine-driven single-voltage generator.

No. 000 sandpaper. Emery cloth should not be used. All sand and metal particles should be removed with compressed air. Lubricants, such as vaseline and grease, should never be put on the commutator or brushes.

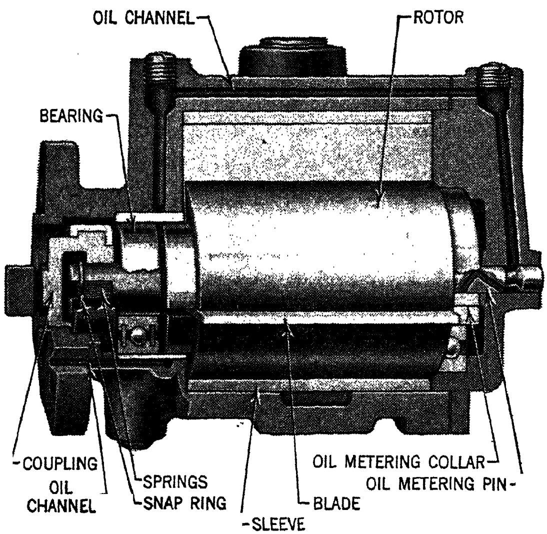
Worn brushes which have reached a limit that will not insure proper operation until the next inspection period should be replaced. When replacing a brush, the new brush should be properly seated by inserting a strip of No. 000 sandpaper between the brush and the commutator with sanded side next to the brush and pulling in the direction of rotation. This operation should be repeated until brush is fully seated.

If a generator fails to function properly, it should be checked first to see that all switches are on and that no fuses are blown. If the trouble is not located, the control box and control box mounting connections should be replaced or inspected. If control box does not appear to be at fault, the generator window strap should be removed for inspection. If none of these inspections reveals the trouble and the continuity of all wiring has been checked, the manufacturer's instructions should be consulted for methods of testing.

PUMPS

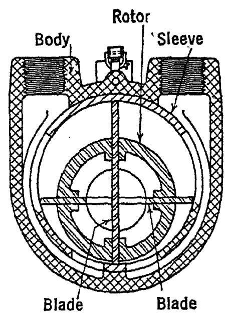
Engine-driven *vacuum pumps* are installed on many engines to provide the suction necessary for operation of certain aircraft flight instruments. The pressure side of the pump may also be used to operate inflatable types of surface de-icers.

Most vacuum pumps are of the vane type, although the Roots blower principle is now being used to some extent. With the vane-type pump a constant supply of oil is necessary to provide lubrication for the vanes. This results in a continuous exhaust of oil from the pressure side of the pump. Although the amount of oil exhausted is small, it must be eliminated from the air by oil separators before the air enters the rubber de-icers. When de-icers are not installed, the pump exhaust



Courtesy Pump Engineering Service Corporation

FIG. 192. Vane-type vacuum pump.

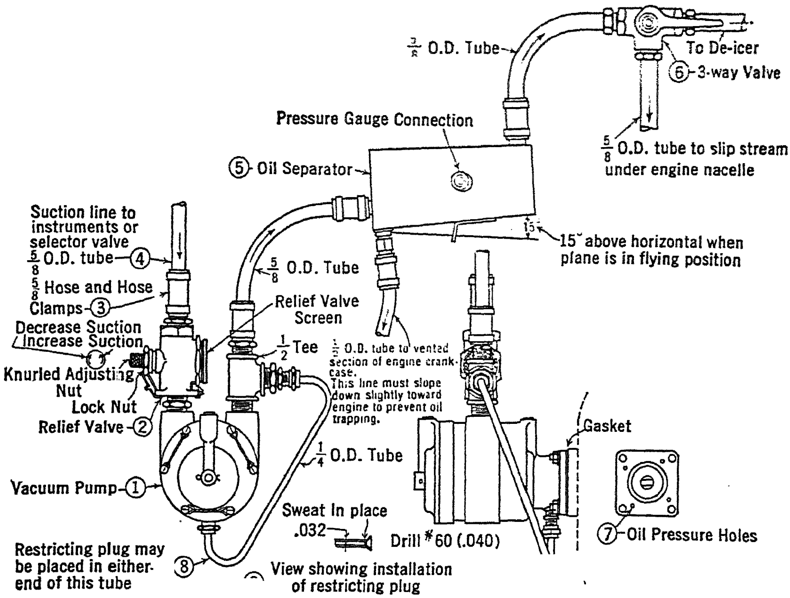


Courtesy Pump Engineering Service Corporation

FIG. 193. Cross-sectional view of vane-type vacuum pump.

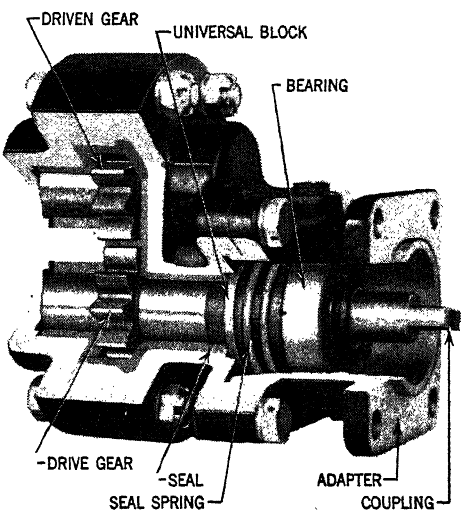
usually empties into the engine exhaust collector, where the oil is burned by the hot gases. The burning of the oil as it enters the collector ring builds up a carbon deposit, which must be cleaned away at regular intervals or else the pump exhaust will become clogged and damage the pump as a result of high pressures if a relief valve is not installed in the pressure line.

Vane-type pumps are lubricated by engine oil pressure. If a lubricating oil hole is not provided in the engine mounting pad, it becomes necessary to install an external oil line. Some pumps incorporate an



Courtesy Pump Engineering Service Corporation

Fig. 194. Installation diagram of a vane-type vacuum pump.



Courtesy Pump Engineering Service Corporation

Fig. 195. Gear-type hydraulic pump.

oil filter for cleaning the incoming lubricating oil. On such pumps the filter should be removed for cleaning at regular intervals. The supply of oil to the pump may be checked by disconnecting the discharge line from the pump and running the engine for a period of at least 10 min at not less than 1000 rpm. A piece of paper held close to the discharge port of the pump will indicate the amount and condition of the oil passing through the pump.

To equalize pressure in the pump coupling chamber the chamber is vented to the pressure outlet of the pump. This aids in reducing oil leakage from the engine drive into the pump, or from the pump into the engine. If the vent is not incorporated in the pump body, it will be necessary to install an external vent line from the vent opening to a tee coupling in the pressure line from the pump.

An engine-driven *hydraulic pump* may be installed to provide the hydraulic pressure necessary for the operation of certain hydraulically operated aircraft mechanisms. Most hydraulic pumps are of the gear type. A pressure relief valve for maintaining a constant outlet pressure may or may not be incorporated in the pump. If not incorporated in the pump a relief valve must be provided elsewhere in the hydraulic system. If properly installed, hydraulic pumps require no special maintenance between overhauls.

CHAPTER X

PROPELLERS

The engine produces power which must be converted into a force to pull the airplane through the air. The propeller is a device for converting the power of the engine into a forward force or thrust. While there are many types of propellers, the air screw propeller has been universally adopted for aircraft use. The air screw propeller, as its name implies, screws its way through the air, advancing as it turns and moving the aircraft with it. As the propeller revolves its forward force is obtained from the reaction of the mass of air which is pushed backwards. The backward-moving air, called the *slip stream,* has kinetic energy by virtue of its motion, and this energy represents a loss. The slip-stream velocity, when compared with the forward speed of the airplane, varies from a minimum of approximately 10 per cent during high speed flight to a maximum per cent during take-off. Any parts of the airplane which are in the slip stream pass through it with a relative speed equal to the airplane's forward speed plus the backward speed of the slip stream. The drag of parts of the airplane in the slip stream is therefore increased. Other losses encountered in the propeller are due to the rotation of the slip stream, the formation of eddies, and the profile drag of the blade. The efficiency of any machine is the proportion of the useful power output to the power input. The efficiency of a propeller is the thrust horsepower divided by the shaft horsepower (brake horsepower) of the engine. Propeller efficiencies vary in normal flight from 50 to 87 per cent.

Nomenclature. The air screw propeller has two or more twisted arms called *blades.* The blades meet at a *hub* or *boss.* The hub is the center of the propeller, and a line through it, about which the blades rotate, is known as the *thrust line* or thrust axis. The hub is provided usually with a splined or keyed hole for securing the propeller to the driving shaft. The edge of the blade which is in the direction of rotation is called the *leading edge;* the other is the *trailing edge.* The surface of the blade which is to the rear is called the *face* or *driving face* of the blade. The surface of the blade toward the front is the *back* or *cambered side* of the blade. The *diameter* of a propeller is the diameter of the circle swept by the blade tips. If the propeller is attached

directly to the engine crankshaft it is called a *direct drive*. If the propeller is attached to a short shaft which is geared to the engine crankshaft it is called a *geared drive*. Geared-drive propellers rotate more slowly than the engine crankshaft. A propeller which pulls the airplane after it is known as a *tractor*, and one which pushes the airplane ahead of it is a *pusher*.

Propeller Action. If a flat plate is held in an air current it is at once apparent that there is a force acting upon it. If the plate is held perpendicular to the direction of air flow, the only force will be the resistance or drag in the direction of the flow. If, however, the plate is inclined at some angle, the force will also be inclined. This inclined force may be resolved into a component perpendicular to the relative flow and a component parallel to the relative air flow. The component perpendicular to the relative air flow is known as the lift and the parallel component as the drag. An airfoil is a body shaped so that the lift is high compared with the drag. Fig. 196 shows the total force, called the resultant force, on an airfoil resolved into the lift and drag components. The point where the resultant force vector intersects the chord or base line of the airfoil section is called the center of pressure. The lift and drag forces on an airfoil are different for each different angle of attack. The lift increases with increased angle of attack up to a certain maximum value, after which it falls off as the angle becomes still greater. The drag has a minimum near 0 deg and increases with increase of angle of attack, becoming very great for the large angles beyond the maximum lift.

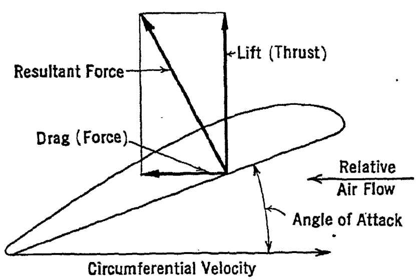


FIG. 196. Lift and drag components of the force on an airfoil section.

If an airplane propeller is revolving but the airplane has no forward movement, the airfoil section of Fig. 196 may be considered as a section of the blade. If the air is considered as standing still, then it has a relative flow when compared to the airfoil, since the airfoil moves into the air as it revolves about the center of rotation. The velocity of any section revolving about a center is known as circumferential velocity, and its magnitude is dependent upon the distance from the center, since the distance it must travel in one revolution increases as its distance from the center increases. The angle at which the face or chord of the airfoil strikes the air is the angle of attack. The relative air flow ex-

erts a force on the airfoil which is shown as the resultant force. This resultant force is resolved into the lift or thrust, which is the force that tends to pull the airplane forward, and the drag which represents the power required to move the airfoil at the velocity at which it is moving circumferentially. An increase in the circumferential velocity will increase the relative air flow which will, in turn, increase the magnitude of the lift and drag. Since the drag increases, it follows that additional power is required to increase the circumferential velocity. The air is given a backward motion by the airfoil section and, as previously stated, the power consumed in imparting backward velocity to this air is lost. This loss will be small when the quantity of air is large. The quantity of air depends on the propeller diameter, the air density and, as will be seen later, the forward speed of the propeller. Hence, for a fixed value of thrust, it is best to use a large-diameter propeller, and the losses will be less at high forward speed and in dense air.

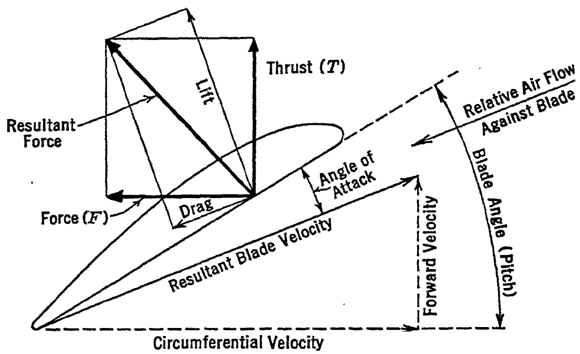


FIG. 197. Thrust and torque components of a propeller airfoil section which has forward as well as circumferential motion.

When a propeller has forward motion the angle of attack is not equal to the blade angle. As the blade moves circumferentially, it is also moving forward. The resultant blade velocity is shown in Fig. 197. The relative air flow is, then, parallel to the resultant velocity and the angle of attack is equal to the blade angle less the path angle. Like any airfoil, this section will have a resultant force dependent upon the angle of attack, the width of the chord, the relative velocity of the air, and the density of the air. The resultant force on the airfoil may be resolved into the lift and drag components. However, the lift and drag components of the airfoil section are not in the directions in which the thrust is desired and the power from the engine is supplied to the propeller. Therefore, it is necessary to resolve the resultant force

into components which are in line with the desired thrust direction and the torque of the engine. These components are shown as thrust T and force F in Fig. 197. The thrust T may be expressed as the pounds pull at some particular speed. The force F may also be expressed as pounds pull at some particular speed. The direction of the force F is opposite to the direction of rotation; this means that a force equal to and opposite to force F is required to move the airfoil section. This force is furnished by the engine.

The thrust of the whole propeller and the power required to turn it at a certain speed may be found by adding together the thrust and force components for each section. Tests, however, are made whenever possible to obtain the thrust and power since calculations by summation of the forces on the sections may be in error because of error in estimating the induced drag and its effects.

Propeller Characteristics. The largest diameter possible is best for a propeller. There are several factors, though, which limit the diameter. Proper clearance must be allowed between the tips and parts of the airplane and also the ground. For the propeller to be stiff and strong the blades must not be too narrow or thin. Hence, exceedingly large-diameter propellers with sufficiently stiff blades are excessively heavy. The tip speed must also be considered. The efficiency decreases rapidly as tip speeds approach the speed of sound.

The smaller the number of blades a propeller has the lighter, more efficient, less expensive, and easier to handle it is. Three- or four-blade propellers may be used where space is limited or where a propeller of fewer blades would have excessive tip speed. A three-blade propeller will run smoother than a two-blade propeller on a geared engine. The more blades a propeller has the more power it will absorb and the more thrust power it will produce, but this will be done less efficiently than by a propeller with fewer blades.

When the blade diameter is limited the blade width may be made large. The power needed by the propeller varies directly as the blade width but as the width continues to increase the efficiency decreases.

Fixed-Pitch Propellers. A fixed-pitch propeller is one whose blade angles cannot be changed during flight. Some, but not all, fixed-pitch propellers can have the blade angle adjusted while on the ground. These may be called adjustable fixed-pitch propellers.

Suppose that a fixed-pitch propeller is turning a certain number of revolutions per second while in level flight. The airplane is put into a climb; this causes it to fly slower. The throttle is not disturbed. By referring to Fig. 197 it will be observed that, since the forward velocity is decreased, the relative air flow is going to strike the propeller blade

at a greater angle of attack. The greater angle of attack, in turn, increases the force F component. The engine is already giving all the power it can to the propeller for that particular throttle setting. Therefore, the propeller must slow down until the force component is equal to the power being supplied. If the airplane were put into a dive the opposite effect would result.

The blade angle or pitch of a fixed-pitch propeller should be such that, in level flight at rated altitude and at rated horsepower, the propeller turns at the rated revolutions of the engine.

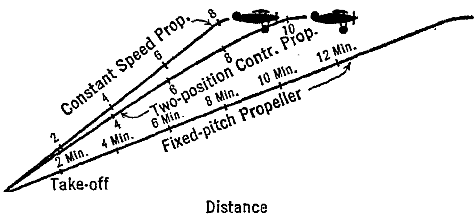
Controllable and Constant Speed Propellers. A fixed-pitch propeller which is suitable for level flight conditions will allow the engine to develop only 75 to 80 per cent of its full power at the low forward speeds of take-off. This is because at low forward speeds the relative flow of air against the blade makes a large angle of attack. (See Fig. 197.) The large angle of attack produces a relatively large force F in relation to the thrust produced. The large force F prevents the engine from turning the number of revolutions necessary for full power. An engine cannot produce full power unless it can turn at the rated speed for full power.

A propeller whose blade angle may be varied in flight is called variously a *controllable propeller,* a *controllable-angle propeller,* or a *controllable-pitch propeller.* The blades of such a propeller are rotated in the hub to change the blade angle. Several methods have been used to accomplish the rotation of the blades. Some controllable-pitch propellers have only two blade angles at which the propeller may be operated; these are known as the high and low pitch settings. The low pitch setting is usually a compromise for best take-off and climb. The high pitch setting is usually for cruising conditions. The pitch setting is controlled from the cockpit. Other controllable-pitch propellers may be operated at any desired angle. The angle may be controlled from the cockpit, or it may be controlled by a governor; in the latter event it is a *constant speed propeller.*

During take-off the controllable-pitch propeller has two advantages. It permits the engine to develop its full power, and the propeller itself is more efficient. As the forward speed of the airplane increases the efficiency of a fixed-pitch propeller becomes greater. Hence, the controllable-pitch propeller does not have much more efficiency than the fixed-pitch propeller during climb. Its main advantage during climb is that it will allow the engine to develop full power. The relative performance of an airplane with a supercharged engine and various types of propellers is shown in Fig. 198.

As we have learned from Chapter II, the power of an unsupercharged

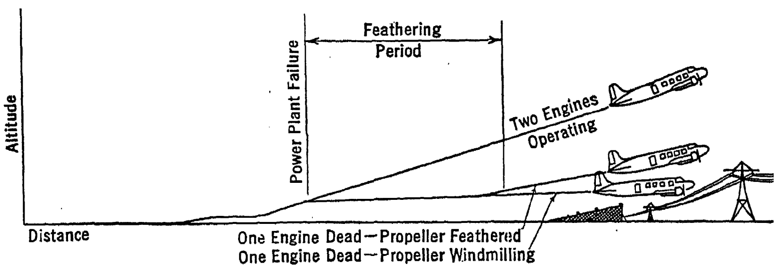
engine falls off as altitude is increased. This decrease in power is somewhat greater than the decrease in air density. The power required to turn a propeller at a certain number of revolutions, with the angle of attack remaining constant, varies directly with the air density.



Courtesy Hamilton Standard Propellers

FIG. 198. Comparative airplane performance with constant speed, two-position, controllable- and fixed-pitch propellers.

Since, as altitude increases, the power of the unsupercharged engine decreases faster than the air density, the propeller will slow down with increase in altitude. A decrease in the blade angle as the altitude increases would prevent the propeller from slowing down and allow



Courtesy Hamilton Standard Propellers

FIG. 199. Comparative twin-engine airplane performance with both engines operating, one engine dead and propeller feathered, and one engine dead and propeller windmilling.

the engine to develop its maximum output for the particular altitude. With the supercharged engine, the opposite is true.

The maximum blade angle change for a two-position propeller is about 20 deg. The constant speed propeller may have a blade angle change of as much as 40 deg for conditions from take-off to cruising at altitude. A propeller which permits the blade angle to be increased to 90° is known as a *feathering* or *full-feathering* propeller. The advantage of a full-feathering propeller is that it is possible to stop ro-

tation of a dead engine of a multiengine airplane while in flight. The resistance offered by a full-feathered propeller is much less than that of a braked or windmilling propeller which is not feathered. Feathering the propeller on a dead engine results in freedom from vibration, improvement in stability, and better performance on the remaining operating engine or engines. The relative performance of a two-engine airplane with and without full-feathered propellers, with one engine dead, is shown in Fig. 199.

Some full-feathering propellers are reversible; that is, the blade angle can be made negative. This negative angle will produce a negative thrust. Perhaps the best utilization of negative thrust is for turning multiengine flying boats in limited areas.

Wooden Propellers. The wooden propeller is still the most popular for use on engines of 300 hp and less. This is probably due to the relative cheapness of the wooden propeller as compared with the metal or composition propellers. The wooden propeller is not made from a single piece of wood, but is built up with several thin planks, or laminations, glued securely together. Birch wood is probably the most widely used in the construction of wooden propellers.

After the carefully inspected and dried planks have been securely glued together under pressure, the propeller is roughly turned to shape by machine. It is then finished by hand. Often the tips and leading edge are covered with a thin metal sheet secured in place with countersunk head wood screws. The heads of the screws are filled with solder and finished off smooth. This metal cover protects the most vulnerable portion of the propeller from the abrasive effect of sand and pebbles which may be picked up while the propeller is running on the ground. The propeller is very carefully balanced on a balancing mandrel. To prevent the penetration of moisture, the propeller is given several coats of varnish. It is finally given an extremely smooth finish to reduce resistance to the air.

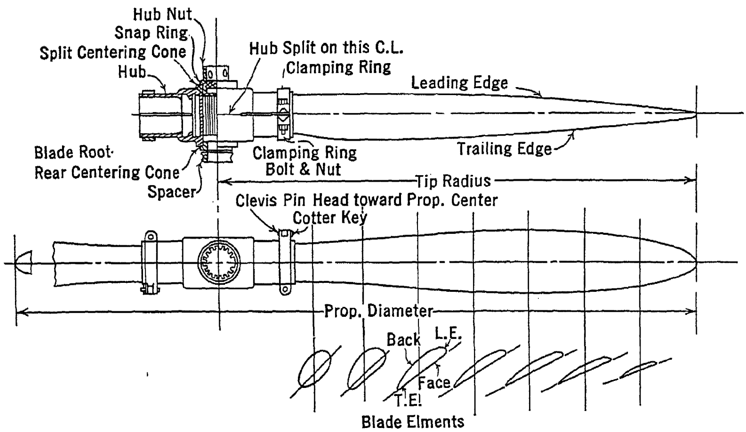
Metal Propellers. Propellers or propeller blades have been made from several different plastics. Through new improvements and technique in plastics, it is expected that plastic propellers will gain in popularity. For engines of 300 hp and above the metal propeller is the most popular.

The most universally used metal for propeller blades is aluminum alloy. The blades are forged from a solid billet of the alloy and then machined, balanced, and polished.

Steel is also used for the construction of blades. Since a solid steel blade would be excessively heavy, it is necessary to make the steel blades hollow. This is done by welding and brazing together the lead-

ing and trailing edge of two steel sheets which have been properly formed. The steel propeller blade is much better able to stand the abrasive effects of sand, pebbles, and cinders than the aluminum alloy blade.

The fixed-pitch aluminum alloy propellers are sometimes forged in one solid piece, including the hub. The blades of the adjustable fixed-pitch propellers are fabricated separately from the hub. The hub is made from a forging of high strength steel, machined and highly polished. It is very essential that all parts of a propeller be highly polished to eliminate scratches or rough surfaces. High stress concentrations are set up in the sharp corners of scratches or rough surfaces which might lead to cracks and ultimate failure of the propeller. Several methods of holding the blades in the hub are in use. A very successful method is shown in Fig. 200. The hub is made in two parts



Courtesy Civil Aeronautics Administration

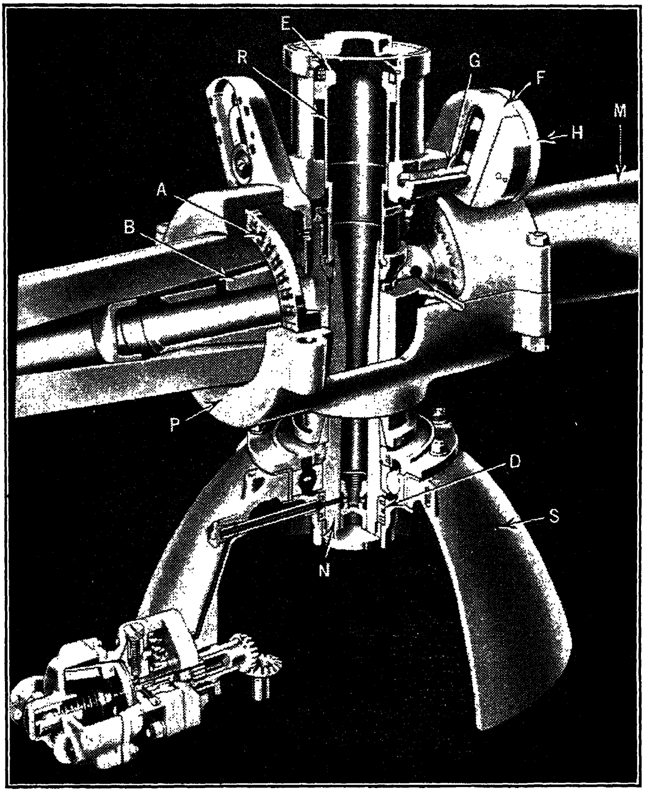
FIG. 200. Propeller nomenclature, fixed-pitch propeller.

and held together by clamp rings. The blade angles may be set as desired before the clamp rings are tightened.

Controllable-Pitch Propeller Construction. The problems encountered in the controllable-pitch propeller are: to hold the blades rigidly, at the same time permitting them to turn easily in the hub, and to provide some means of controlling the angle of the blades while the hub is rotating. There are several methods in use for controlling the blade angle.

Hamilton Standard Controllable-Pitch Propellers. The earlier Hamilton Standard controllable-pitch propellers depend upon a hydraulic pressure in a cylinder, to change the pitch in one direction, and

counterweights connected to the blades to change the pitch in the other direction. Fig. 201 shows a cutaway view of this type of propeller. The blades M are upset on the root end to provide a shoulder for a race which rides against the bearings A. The other face of the bearings rides against a race which rests on the inward flanged ends of the hub P. The hub is made in two sections and held together with bolts. The spider B fits closely in the hollow root of the blades and imparts rigidity

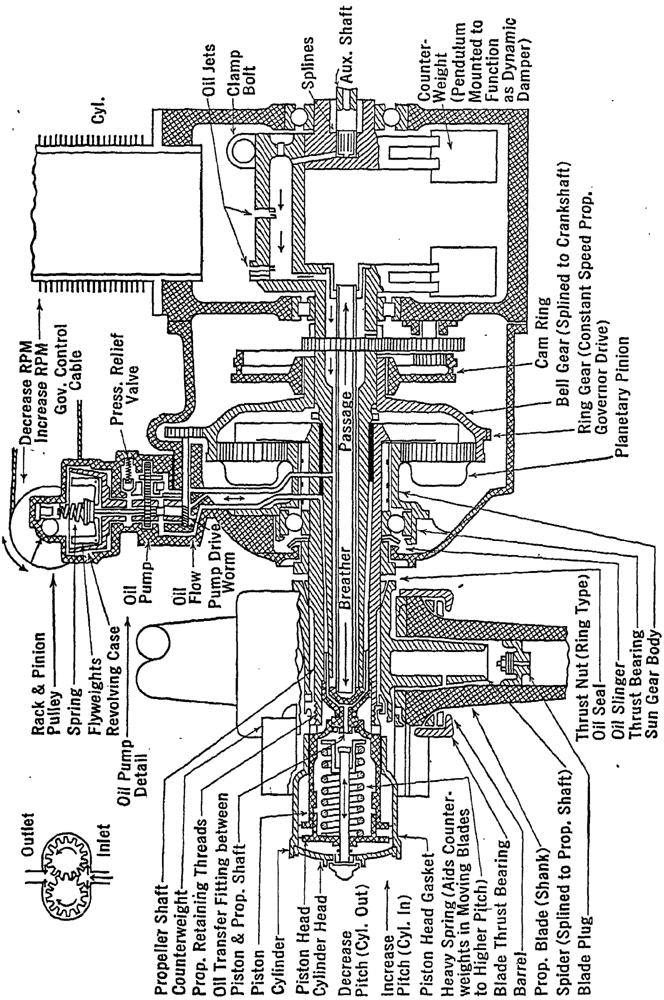


Courtesy Hamilton Standard Propellers

FIG. 201. Cutaway view of the Hamilton Standard counterweight-type controllable-pitch propeller.

to them. The hub is held onto the engine shaft N (shown cut off) by the long nut R. The shaft and nut are hollow to allow an oil passage to the inside of the cylinder E. The cylinder is connected by link bolts to the slots in the counterweights F, which are in turn rigidly connected to the blades. Engine oil under pressure, if allowed to pass through the

hollow shaft and to the cylinder E, will cause the cylinder to move forward. As the cylinder moves forward the link bolts move forward in the slots H and change the blade angle, in this instance decreasing it. If the oil is allowed to drain back into the engine, the centrifugal force



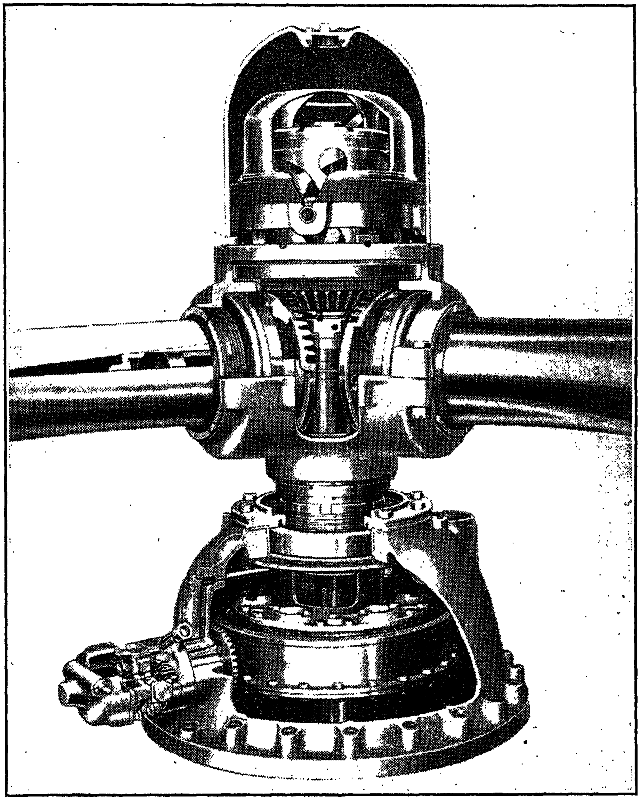
Courtesy Civil Aeronautics Administration

on the counterweights moves them outward from the axis of rotation, thus twisting the blades to increase the blade angle and at the same time moving the cylinder inward.

For the two-position propeller the oil pressure is furnished by the

engine oil pump and is controlled by a small cockpit operated valve. For the constant speed propeller the oil pressure is furnished and controlled by the propeller governor, which will be discussed later in this chapter.

Hamilton Standard Hydromatic Propeller. A cutaway of the Hamilton Standard Hydromatic propeller is shown in Fig. 203. The



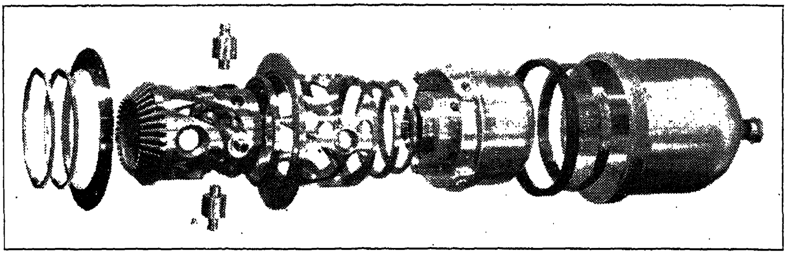
Courtesy Hamilton Standard Propellers

FIG. 203. Cutaway view of the Hamilton Standard full feathering Hydromatic propeller.

dome section only is shown expanded in Fig. 204. The hub, blade bearings, blades, and spider are similar to those of the counterweight type of propeller. There are no counterweights on the Hydromatic propeller. The cylinder does not move, but it is securely fastened to the hub. The pitch-changing mechanism, by which oil forces are translated into

blade-twisting moments, consists essentially of a double-acting piston in a cylinder, a pair of coaxial cylindrical cams and bevel gears between the rotating cam and the blades. The external cam remains stationary with respect to the hub.

The constant speed control is a governor of the centrifugal flyball type. It incorporates a gear pump to boost the engine oil to the re-

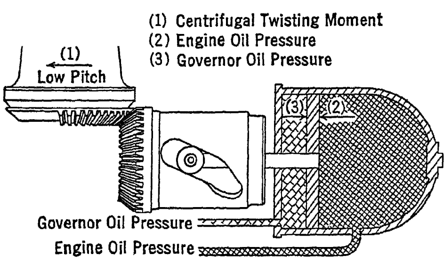


Courtesy Hamilton Standard Propellers

FIG. 204. Exploded view of the dome section of the Hamilton Standard Hydromatic propeller.

quired pressure, and a pilot valve, which is sensitive to changes in engine rpm to meter oil to or from the propeller in order to adjust the blade angle as required for the maintenance of constant engine speed.

A diagram of the forces which control the blade angle for constant speed operation is shown in Fig. 205. The external stationary cam is left off Fig. 205 for clearness. The three fundamental forces are:



Courtesy Hamilton Standard Propellers

FIG. 205. Diagram of propeller control forces of the Hydromatic propeller.

1. *Centrifugal twisting moment of the blades toward low pitch,* which is utilized to decrease the blade angle. This moment, about the longitudinal blade axis, is the result of a force couple consisting of the resultant of components of centrifugal force acting on the mass of the blade on either side of its longitudinal axis. This centrifugal moment is modified by the aerodynamic twisting moment of blade which, during normal level flight, is relatively small and acts toward high pitch, tending to reduce, to some extent, the net twisting moment toward low pitch.

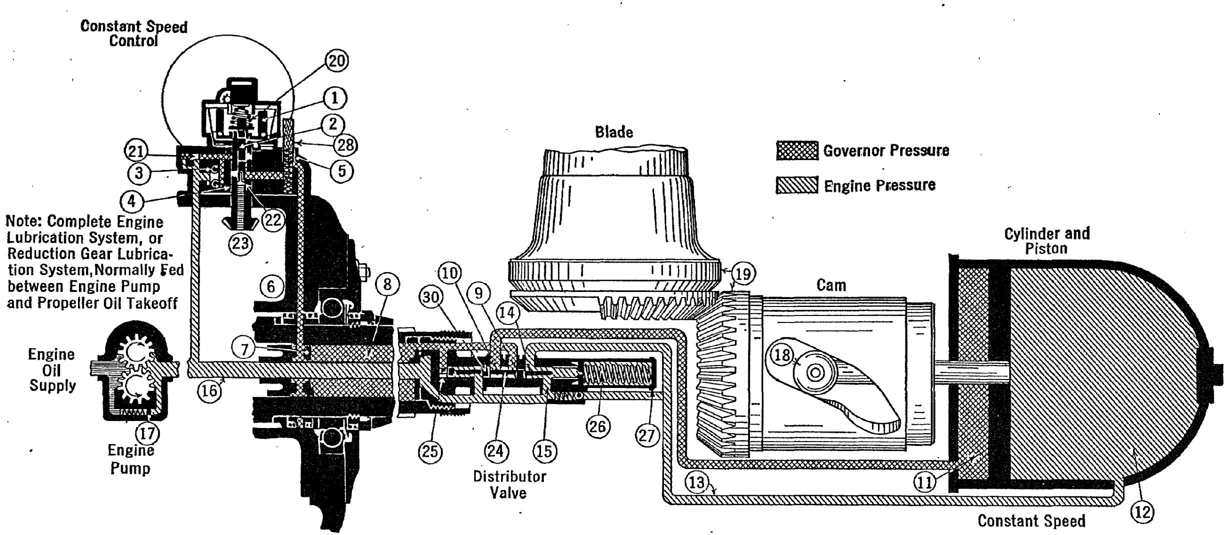
2. *Engine oil under normal engine pressure,* which supplements the centrifugal moment, thus insuring adequate control force toward low pitch at low propeller speeds.

3. *Engine oil under boosted pressure from the governor,* which moves the blades toward high pitch.

The necessary balance between these control forces is maintained by the propeller governor which, in addition to boosting the engine oil pressure, meters to, or drains from, the propeller the quantity of oil required to maintain the proper angle for constant speed operation.

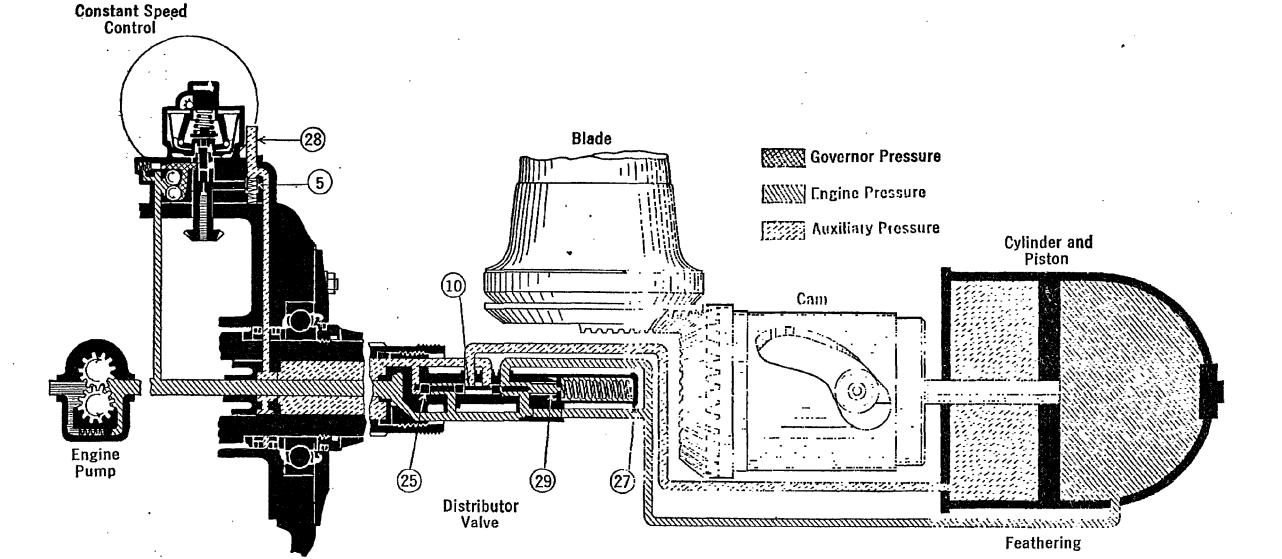
Constant Speed Operation. By referring to Fig. 206(*a*), one can see that the operation is as follows. Should the engine speed increase to an rpm above that for which the governor is set, the governor flyweights (1) move outward, raising pilot valve (2) and admitting oil from the governor pump (3) into the hollow driveshaft (4). From the driveshaft, the oil flows through the governor cut-off valve (5), through the engine transfer rings (6), the air separator plugs (7), the shaft (8), and through the propeller distributor valve ports (9) and (10) into the inboard end of the cylinder (11). When the pressure on the inboard side of the piston exceeds the combined forces toward low pitch, plus the mechanical friction of the mechanism, the piston moves outward, and oil in the outboard end of the cylinder is displaced into the engine lubricating system, its path being from the cylinder at (12) through tube (13), past the distributor valve ports (14) and (15) and into the engine shaft tube (16). From this point the pressure is dissipated by the leakage of oil past the engine bearing clearances, or through the engine pump relief valve (17). The outward motion of the piston is translated, by means of cam rollers (18), into rotary motion of the cam which, through bevel gears (19), increases the blade angle. The increase in blade angle is accompanied by a decrease in engine revolutions per minute, and because of decreased centrifugal force the governor flyweights move inward under the action of spring (20), lowering the pilot valve until, when the engine is again running at the speed for which the governor is set, the supply of governor oil to the propeller is completely cut off, and the engine continues to run *On Speed.* The output of the governor pump is now discharged through the relief valve (21) back into the intake side of the governor.

When the engine speed drops below the rpm for which the governor is set, the flyweights move inward, lowering the pilot valve and allowing oil from the inboard end of the cylinder to flow back through the distributor valve and shaft passages into the governor, whence it is discharged, through governor drain port (22), into the engine nose



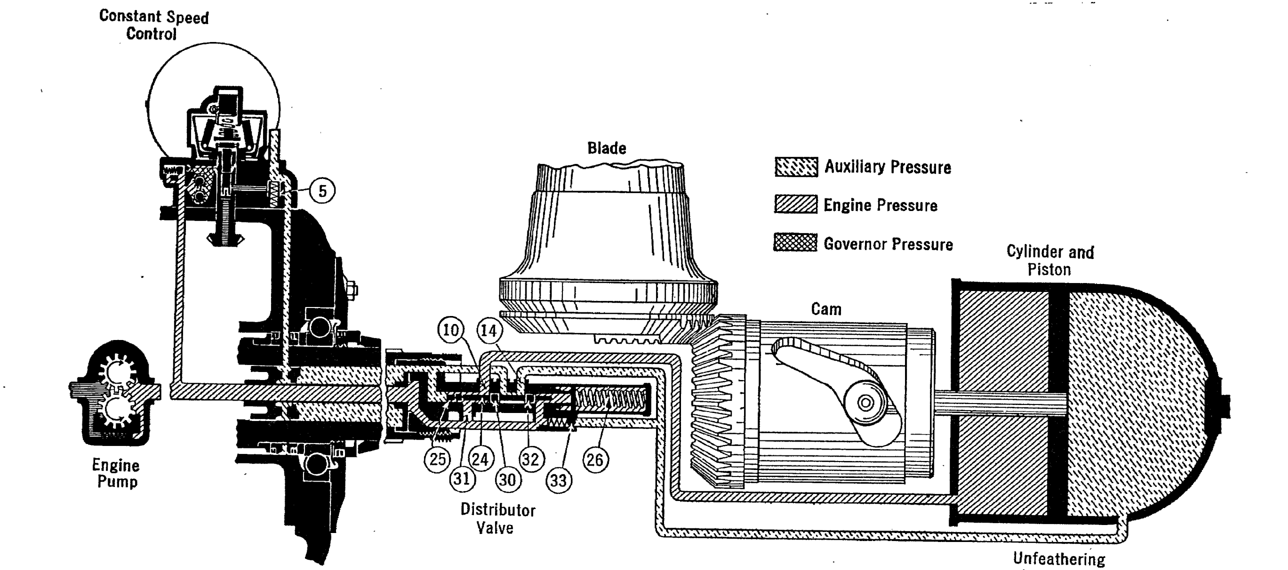
1. Governor Flyweight
2. Governor Pilot Valve
3. Governor Pump
4. Hollow Drive Shaft
5. Governor Cut-Off Valve
6. Engine Shaft Oil Transfer Rings
7. Propeller Shaft Air Separator Plug
8. Propeller Shaft Oil Passage
9. Distributor Valve Port
10. Distributor Valve Port
11. Propeller Cylinder (Inboard End)
12. Propeller Cylinder (Outboard End)
13. Oil Supply Tube (Outboard Cylinder End) (Schematic Only)
14. Distributor Valve Port
15. Distributor Valve Port
16. Engine Oil Pressure Supply Tube
17. Engine Pump Relief Valve
18. Cam Slot Rollers
19. Bevel Gears
20. Governor Control Spring
21. Governor Relief Valve
22. Governor Drain Port
23. Governor Drive Gear
24. Propeller Distributor Valve
25. Propeller Distributor Valve
26. Distributor Valve Spring
27. Distributor Valve Spring Housing
28. External High Pressure Oil Line
29. Distributor Valve (Outboard End)
30. Distributor Valve Land
31. Distributor Valve Port
32. Distributor Valve Land
33. Dome Pressure Relief Valve

FIG. 206(*a*). Schematic diagram showing the operation of the Hydromatic propeller. Distributor valve is in position for constant speed operation.



1. Governor Flyweight
2. Governor Pilot Valve
3. Governor Pump
4. Hollow Drive Shaft
5. Governor Cut-Off Valve
6. Engine Shaft Oil Transfer Rings
7. Propeller Shaft Air Separator Plug
8. Propeller Shaft Oil Passage
9. Distributor Valve Port
10. Distributor Valve Port
11. Propeller Cylinder (Inboard End)
12. Propeller Cylinder (Outboard End)
13. Oil Supply Tube (Outboard Cylinder End) (Schematic Only)
14. Distributor Valve Port
15. Distributor Valve Port
16. Engine Oil Pressure Supply Tube
17. Engine Pump Relief Valve
18. Cam Slot Rollers
19. Bevel Gears
20. Governor Control Spring
21. Governor Relief Valve
22. Governor Drain Port
23. Governor Drive Gear
24. Propeller Distributor Valve
25. Propeller Distributor Valve
26. Distributor Valve Spring
27. Distributor Valve Spring Housing
28. External High Pressure Oil Line
29. Distributor Valve (Outboard End)
30. Distributor Valve Land
31. Distributor Valve Port
32. Distributor Valve Land
33. Dome Pressure Relief Valve

FIG. 206(*b*). Schematic diagram showing the operation of the Hydromatic propeller. Distributor valve is in position for feathering.



1. Governor Flyweight
2. Governor Pilot Valve
3. Governor Pump
4. Hollow Drive Shaft
5. Governor Cut-Off Valve
6. Engine Shaft Oil Transfer Rings
7. Propeller Shaft Air Separator Plug
8. Propeller Shaft Oil Passage
9. Distributor Valve Port
10. Distributor Valve Port
11. Propeller Cylinder (Inboard End)
12. Propeller Cylinder (Outboard End)
13. Oil Supply Tube (Outboard Cylinder End) (Schematic Only)
14. Distributor Valve Port
15. Distributor Valve Por
16. Engine Oil Pressure Supply Tube
17. Engine Pump Relief Valve
18. Cam Slot Rollers
19. Bevel Gears
20. Governor Control Spring
21. Governor Relief Valve
22. Governor Drain Port
23. Governor Drive Gear
24. Propeller Distributor Valve
25. Propeller Distributor Valve
26. Distributor Valve Spring
27. Distributor Valve Spring Housing
28. External High Pressure Oil Line
29. Distributor Valve (Outboard End)
30. Distributor Valve Land
31. Distributor Valve Port
32. Distributor Valve Land
33. Dome Pressure Relief Valve

FIG. 206(c). Schematic diagram showing the operation of the Hydromatic propeller. Distributor valve is in position for unfeathering.

housing at (23). Under the action of centrifugal twisting moment and engine oil pressure, the blades now assume a lower angle, the engine speed increases, and the pilot valve rises because of the outward motion of the flyweights. When the engine has reached the rpm for which the governor is set, the pilot valve again assumes a neutral position, neither admitting oil to, nor draining it from, the propeller cylinder. The forces are now in equilibrium and again the propeller runs *On Speed.*

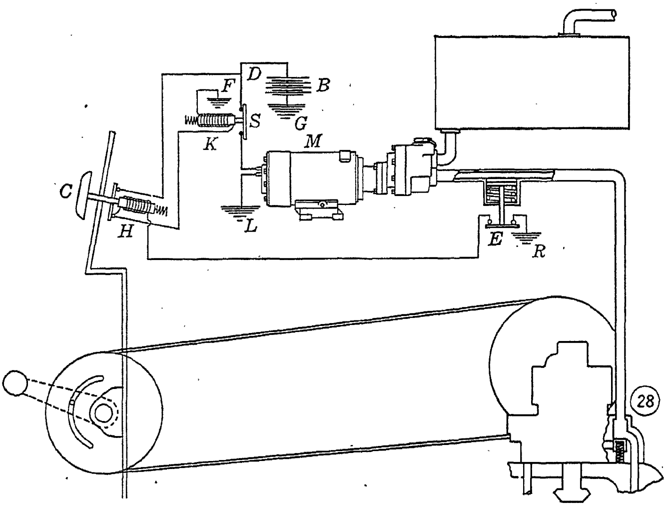
The sensitivity of the entire propeller-governor system is such that a deviation of 2 or 3 rpm from the speed for which the governor is set is sufficient to bring into action the forces necessary to return the system to the *On Speed* condition.

The net pressure available for moving the blades to a higher angle is, of course, the difference between the pressure on the inboard and outboard sides of the piston. This net pressure might vary considerably with variations in engine oil pressure, were the governor relief valve not balanced to prevent such variations. It will be noted that engine oil is directed to the rear side of the governor relief valve (21), to aid the relief valve spring, at substantially the same pressure under which it enters the outboard end of the cylinder. Thus, the maximum net pressure available to move the piston toward high pitch is approximately equal to that for which the governor relief valve spring is set, and is independent of the back pressure in the outboard end of the cylinder.

Feathering Operation. During constant speed operation only the steep portion of the cam slots, where the mechanical advantage is high, is utilized. For the feathering operation the low mechanical advantage portion of the cam slots is utilized. To supply the pressure necessary for feathering and unfeathering, an auxiliary pressure supply system not controlled by the governor is necessary. There are several types of auxiliary pressure systems which may be used.

When using an individual pump system, shown diagrammatically in Fig. 207, the only operation required of the pilot to feather the propeller is to push in the propeller control switch *C*. This closes the electrical circuit from ground *G* through battery *B*, switch *C*, and solenoid switch *S* to ground *F*, thus closing the switch at *S* to complete the circuit *G-B-D-S-M-L* and start the pump. At the same time, holding coil *H* is energized through circuit *G-B-D-H-E-R*. This maintains switch *C* closed without further attention from the pilot and the pump continues to run, supplying oil to governor cut-off valve (5), Fig. 206(*b*), through external line (28), Fig. 207. At a pressure of approximately 150 lb per sq in. valve (5) disconnects the governor

from the system by closing the governor port. Simultaneously, the valve connects the pump with the inboard end of the propeller cylinder by means of the identical passages which formerly were used to conduct governor oil to the propeller for constant speed operation. The piston moves toward the outboard end of the cylinder, and the blades are feathered at a speed proportional to the rate at which oil is supplied to



Courtesy Hamilton Standard Propellers

FIG. 207. Schematic diagram of one type of auxiliary control system for Hydromatic propeller feathering and unfeathering operation.

the cylinder. The pressure in the system during the feathering stroke is determined by the mechanical friction and the blade-twisting moment. In any event the pressure is less than 400 lb per sq in. During the outward motion of the piston, oil in the outboard end of the cylinder is displaced into the engine lubricating system through the same passages as during constant speed.

Having reached the full-feathered position, further movement of the mechanism is prevented by the positive high pitch stops on the rotating cams. The pressure in the inboard cylinder end and in the passages connecting it with the pump now increases rapidly, and upon reaching a value of 400 lb per sq in. opens the pressure cut-out switch *E* (Fig. 207). This de-energizes holding coil *H*, allowing the control switch *C* to return to the off position. This, in turn, de-energizes the coil *K*, breaking the motor circuit and stopping the pump. The pressure in both ends of the propeller drops to zero and the propeller

remains in the feathered position by virtue of balanced forces on the blades.

It will be noted that the distributor valve (24), Fig. 206(*b*), does not function during the feathering operation. As during constant speed, the spring housing (27) remains connected with the outboard cylinder end. This allows any back-pressure in this end of the cylinder to act also on the outboard end of the distributor valve at (29), assisting the spring (26), and increasing by an equal amount the pressure required at the inboard end of the valve at (25) to close port (10). This insures that a maximum pressure difference of 400 lb per sq in. will be available for moving the piston in the feathering direction regardless of the back-pressure it may encounter in forcing the oil from the outboard end of the cylinder into the engine lubricating system.

Unfeathering the propeller consists essentially in reversing the passages in the distributor valve in order to permit the high pressure oil from the auxiliary system to act on the outboard end of the piston, while the inboard end is connected to the engine lubricating system.

To unfeather, it is necessary only to close the propeller control switch *C* (Fig. 207) and hold it closed until the propeller is unfeathered to the desired rpm. In this case the pump motor circuit is completed in exactly the same manner as during the feathering operation, and the pressure is again delivered to the propeller supply passages and the inboard cylinder end. As this pressure increases through 400 lb per sq in. pressure, cut-out switch *E*, Fig. 207, opens and de-energizes holding coil *H*. This, however, does not break the pump circuit, as the pilot continues to hold control switch *C* closed. Also, as the pressure in the distributor valve passages increases, distributor valve (24), Fig. 206(*c*), moves outward against spring (26) under the action of the pressure on its inboard end at (25). When this pressure increases through 400 lb per sq in., land (30) on the distributor valve passes port (10), shutting off the connection between the pump and the inboard cylinder end, and at the same time connecting this end of the cylinder with the engine lubricating system through ports (10) and (31). As the pressure increases further, the distributor valve continues to move outward until, at 500 lb per sq in., land (30) just uncovers port (14) and admits the high pressure oil from the pump to the outboard end of the cylinder. At 600 lb per sq in. the valve assumes the position shown in Fig. 206(*c*), ports (10) and (14) being full open.

With the inboard end of the cylinder connected with the engine lubricating system, and high pressure on the outboard end of the piston, the piston moves inward, unfeathering the blades and forcing the oil on its inboard end into the engine lubricating system. As the blades

are unfeathered, they begin to windmill, and unfeathering is assisted by the centrifugal blade moment. When the engine has reached a reasonable rpm (depending on the blade design, engine-propeller gear ratio and air speed), the control switch *C* is released. This discontinues the high pressure oil from the pump and allows the propeller distributor valve (24) and the governor cut-off valve (5) to return to their normal positions as shown in Fig. 206(*a*). The governor is again connected with the inboard end of the cylinder and constant speed operation is automatically resumed at the rpm for which the governor is set.

Hydromatic Propeller Constant Speed Control. The Hydromatic propeller constant speed control is a governor of the centrifugal flyball type. It incorporates a gear pump to boost the engine oil to the required pressure and a pilot valve, which is sensitive to changes in engine revolutions per minute, to meter the oil to or from the propeller in order to adjust the blade angle as required for the maintenance of constant engine speed. The governor is a self-contained unit suitable for mounting on the special built-in pad on the nose of the engine.

The diagrams in Fig. 208 illustrate the positions and functions of the various parts of the control during the on-speed, underspeed, overspeed, and "in and out of feather" conditions.

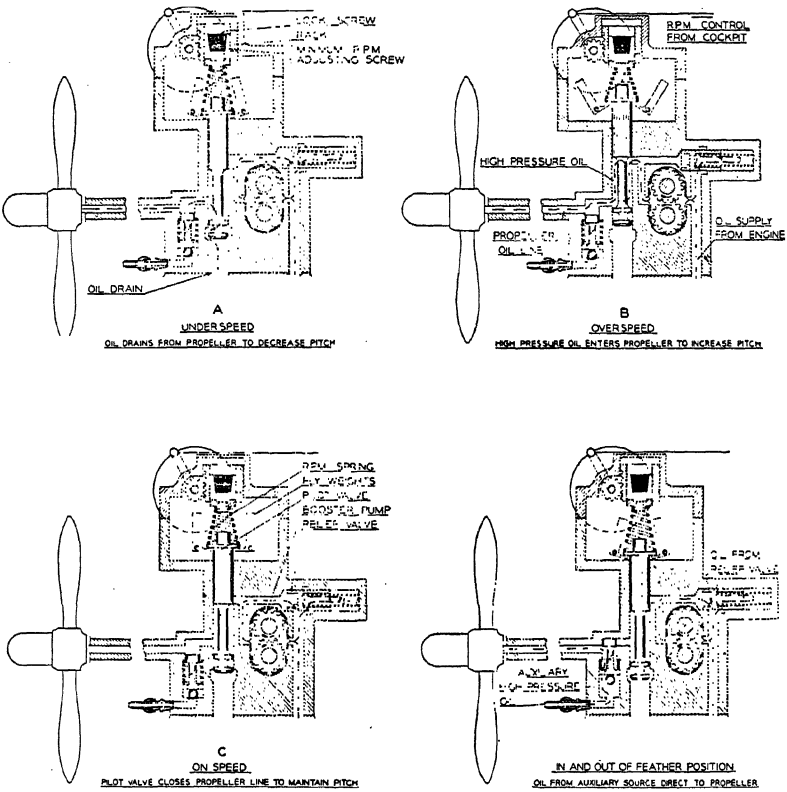
The on-speed condition as illustrated in diagram *C* exists when the flyball and spring forces are in balance, causing the pilot valve to close the line to the propeller and maintain a given blade angle. Both the pressure and drain ports are closed during this condition. All the oil from the gear pump is being by-passed through the relief valve back to the inlet side of the pump.

The underspeed condition, as shown in diagram *A*, exists when the speed of the flyballs has been reduced, and the spring force overcomes the force of the flyballs. In this condition the spring forces the pilot valve down. The upper land of the valve moves below the metering port in the drive gear and cuts off the high pressure oil, and the lower land moves into the recess in the gear and opens the propeller line to drain. When oil drains from the rear of the Hydromatic propeller piston, the blades assume a lower angle and permit the engine speed to return to the original value; the flyballs and speeder spring in the control unit return to a balanced state as shown in the on-speed condition.

In the overspeed condition, as shown in diagram *B*, the speed of the flyballs has increased, and their force has exceeded the force of the speeder spring and the pilot valve is raised. The upper land on the valve then opens the ports through which the high pressure oil flows

and the low land closes the drain. Since oil to the rear of the propeller piston increases the blade angle, the engine speed is thus reduced, and the flyball spring forces return again to a balanced state, as shown in the on-speed condition.

During the feathering and unfeathering operations of the propeller,



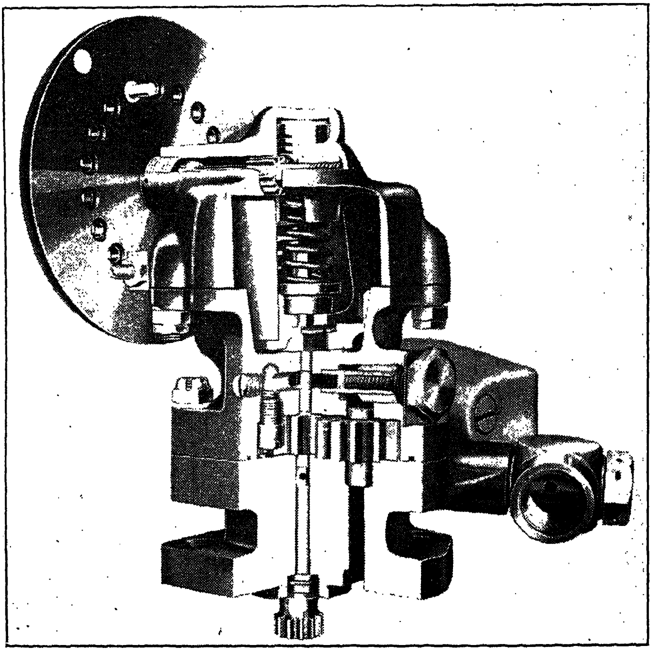
Courtesy Hamilton Standard Propellers

FIG. 208. Schematic diagram of constant speed control unit operation, Hydromatic propeller type.

high pressure oil from an auxiliary source is supplied to the propeller through a transfer valve in the base of the constant speed unit. The function of this valve is to cut off oil from the unit to the propeller and open the passages through the engine nose to the high pressure feathering oil. The valve assembly consists of a plunger, a return spring, and a ball check. The auxiliary high pressure oil forces the plunger against the spring as shown in diagram *D*. When either operation is com-

pleted and the pressure at the source of the auxiliary oil supply is reduced, the spring returns the ball to its seat and reopens the propeller line to governor oil.

The operation of the governor used with the counterweight type of propeller is similar to the Hydromatic. Metering oil to the counterweight type of propeller, though, decreases the blade pitch and causes

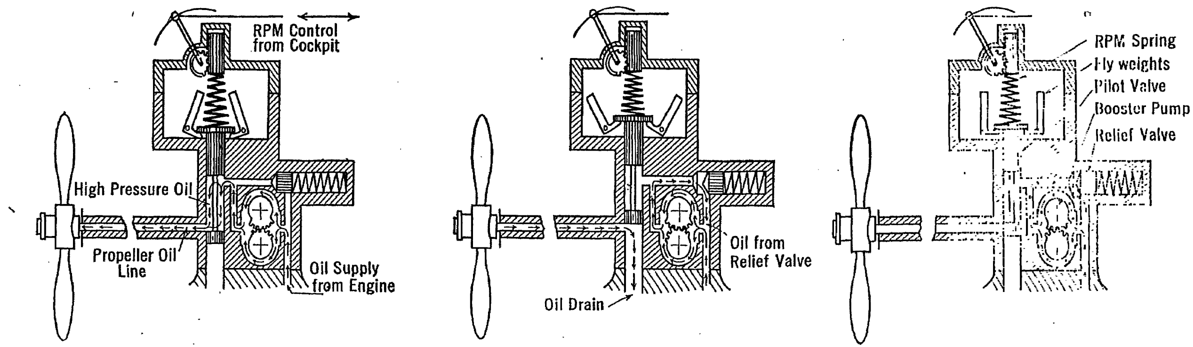


Courtesy Hamilton Standard Propellers

FIG. 209. Cutaway view of Hydromatic type of constant speed control unit.

the engine speed to increase. The pilot valve, therefore, must be designed so that an increase in engine speed will drain oil from the propeller, rather than meter it to the propeller, as in the Hydromatic governor. The operation of the governor used with the counterweight type of propeller is illustrated in Fig. 210.

Curtiss Electric Propeller. The Curtiss electric propeller is operated electrically from the airplane electrical power supply; thus its pitch-changing system is completely divorced from dependence upon the engine. The electrical energy for controlling the propeller blade angles passes through brushes mounted in a housing attached to the engine nose, to slip rings mounted on the rear of the propeller hub, and thence



UNDERSPEED—High Pressure Oil Enters Propeller Line to Decrease Pitch

OVERSPEED—Oil Drains from Propeller to Increase Pitch

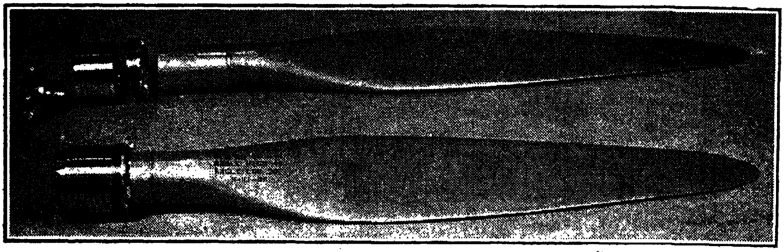
ON SPEED—Pilot Valve Closes Propeller Line to Maintain Pitch

Courtesy Hamilton Standard Propellers

FIG. 210. Schematic diagram of constant speed control unit operation, counterweight-propeller type.

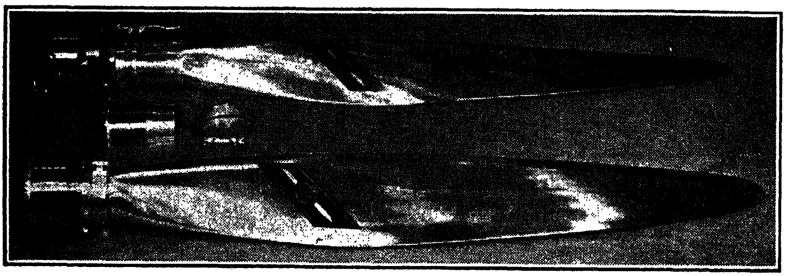
to the pitch-changing motor by way of connector leads in the hub and speed reducer.

The electric pitch-changing motor controls the angle of blade setting through a two-stage planetary gear speed reducer which drives a power bevel gear. This gear meshes with a bevel gear on the shank of each of the blades. Reversibility of pitch change is accomplished through a double-field winding in the electric motor; that is to say, the electric motor is designed to operate in either a clockwise or a counterclockwise direction.



Courtesy Curtiss Propeller

FIG. 211(*a*). Steel blade assembly of the Curtiss electric propeller.

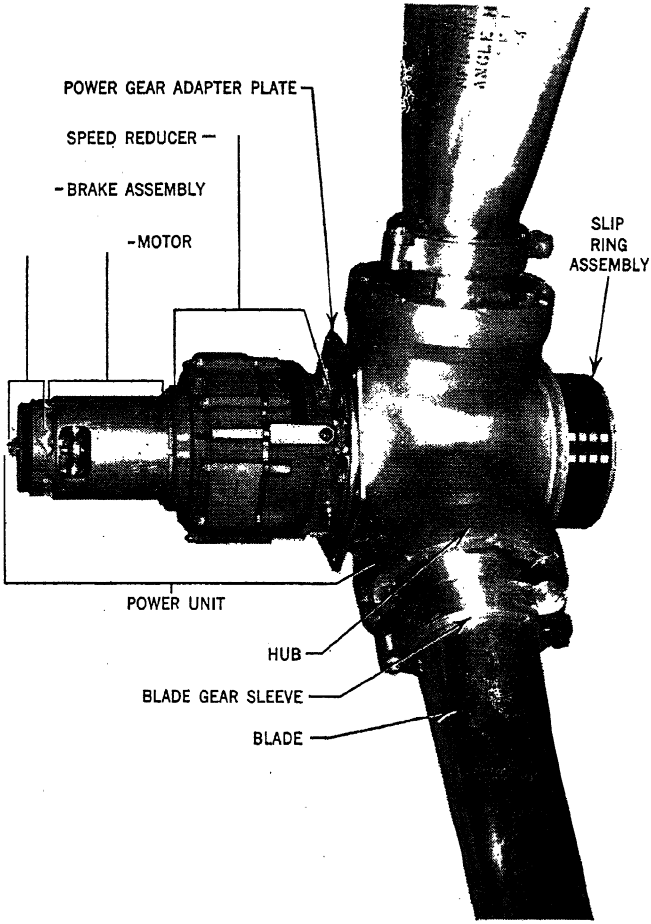


Courtesy Curtiss Propeller

FIG. 211(*b*). Aluminum alloy blade assembly of the Curtiss electric propeller.

The two types now in general use differ from each other in the construction of the blades, aluminum alloy blades being used in one, and hollow steel blades in the other. The root of the aluminum alloy blade is clamped in a split steel sleeve which has a bevel gear machined on one of its halves (Fig. 211). The steel blade has a bevel gear screwed into the root end and pinned in place. Similar stacks of matched ball bearings having angular contact-type races are placed on either type of blade assembly and each assembly is held in the hub barrel by a blade-retaining nut. A grease seal is placed in the blade-retaining nut to hold the lubricant within the hub.

The pitch-changing mechanism or so-called power unit (Fig. 213) consists of a number of subunits. These are individually described as follows:

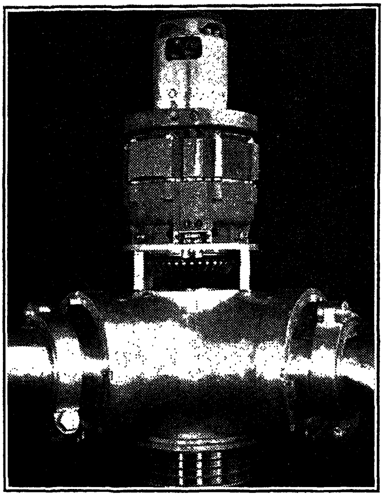


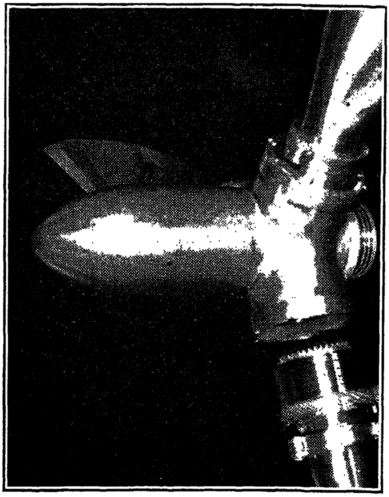
Courtesy Curtiss Propeller

FIG. 212. Unit designations of the Curtiss electric propeller.

The *power gear assembly* consists of a splined bevel gear which meshes with the blade gears; a ball bearing which takes the power-gear thrust, and an adapter plate in which the power gear and bearing are mounted.

The *speed reducer* consists of a two-stage planetary type of gear reduction unit contained within aluminum alloy housings. The speed





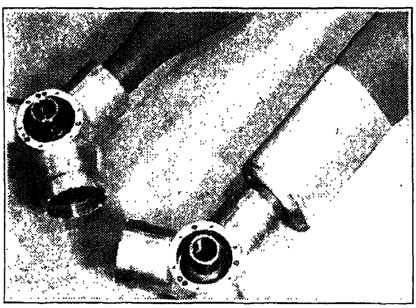
Courtesy Curtiss Propeller

FIG. 213. Power unit removed.

FIG. 214. Blade assembly removed.

reducer is oiltight and is partially filled with oil. Thus the gears and bearings operate continually in an oil bath.

At the hub end of the speed reducer are located the *blade angle limit switches*. These switches are provided to limit the high and low pitch for the flight range and also to stop the pitch change at the feather position. The high and low pitch limit switches are effective while operating on constant speed. The feather cut-out switch is effective only during the feather operation or when increasing pitch manually. Feathering is accomplished with a separate circuit which by-passes the flight range high pitch limit switch. This circuit is used for feathering and for manual increase pitch control.



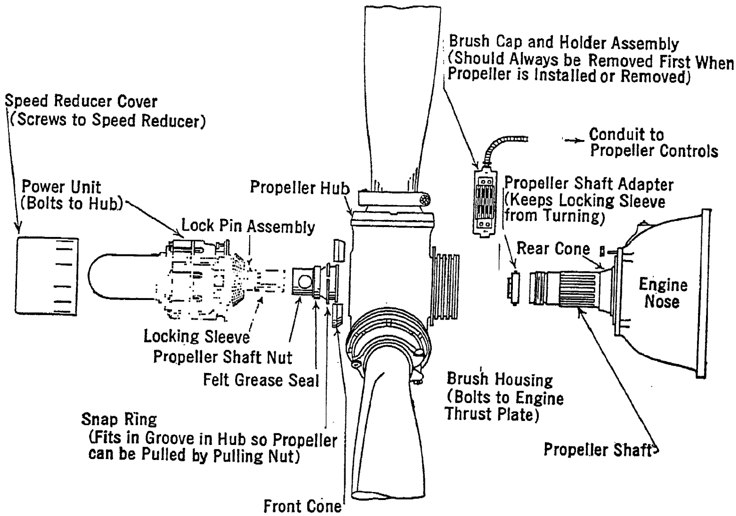
Courtesy Curtiss Propeller

FIG. 215. Blades with and without cuffs. Cuffs increase the cooling effect on the engine, especially while the airplane is standing still or has slow forward motion.

A *mechanical low limit stop* is provided at the hub end of the speed reducer to prevent the propeller blades from flattening out in the event of a mechanical failure. This stop is set to take effect slightly below the electrical low limit switch.

The *electric pitch-changing motor* is mounted to the front housing of the speed reducer. The motor armature is keyed to the driving pinion of the high speed stage of the speed reducer. The motor is series wound and has a double field winding which makes it reversible. The leads are taken through passages in the speed reducer to the limit switches.

A *no-voltage brake* is mounted on the front of the pitch-changing motor. It consists of a brake disc keyed to the armature shaft and a steel brake plate mounted behind the brake disc and held against it by



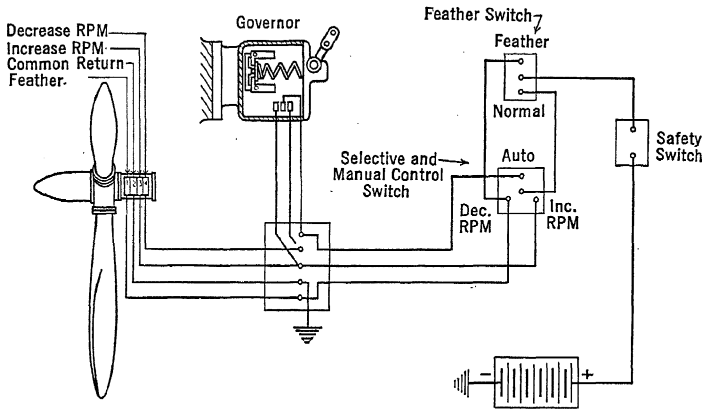
Courtesy Curtiss Propeller

FIG. 216. Schematic diagram of Curtiss electric propeller.

6 coil springs. The steel brake plate is pulled away from the disc by an electric solenoid, the coil of which is connected in series with the electric motor circuit. The purpose of this brake is to stop instantaneously the rotation of the motor armature when the pitch-changing current is cut off. The braking action is effective at all times when the pitch is not being changed; therefore the brake also acts as a definite lock which prevents the pitch from being changed by the blade-twisting forces.

Curtiss Propeller Controls. The control system of the Curtiss electric propeller consists of a constant speed governor, constant speed cockpit control, and cockpit switches (Fig. 217). The purpose of the governor is to maintain the engine at a selected constant speed by controlling the propeller blade angle to correct for varying conditions of

operation such as engine power, airplane speed, and air density. There are two general types of governors now in use. The operation of both types is very similar. Both utilize flyweight force to operate a three-position switch (increase switch, decrease switch, and off position) by means of which the current to the electric motor is regulated, and the blade angles are thereby controlled. The early type of governor is driven by a flexible shaft from a suitable accessory drive on the engine. Through a quarter-ampere control circuit, this type of governor operates



Courtesy Curtiss Propeller

FIG. 217. Schematic wiring diagram of typical Curtiss electric propeller control system.

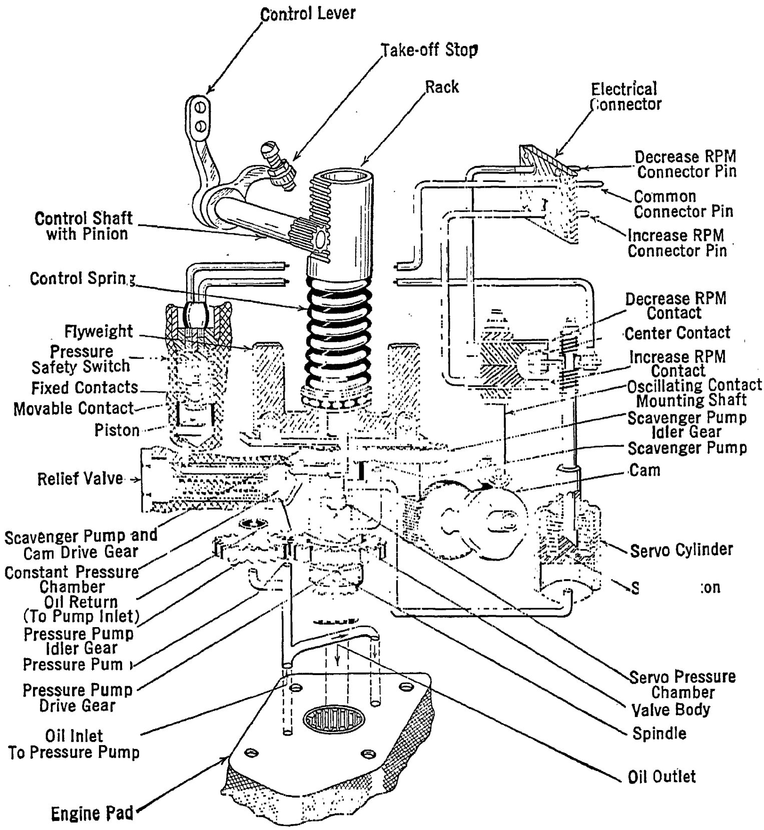
a relay which switches the current to the pitch-changing motor. The later type of governor, known as the proportional governor (Fig. 218), mounts on the nose section of the engine. This type of governor moves its contacts by means of a servo mechanism which is controlled by the flyweights. Contacts in the proportional governor are capable of handling the full pitch-changing motor current; therefore a relay is not required.

During constant speed operation the governor does the switching of current to the pitch-changing motor. Any variation in speed of the flyweights which are driven by the engine will automatically operate the switch in the governor, thereby causing the propeller blade angles to increase or decrease pitch, whichever is necessary to maintain the selected constant speed.

During manual selective operation, the propeller is essentially a fixed-pitch propeller which is controllable through a momentary contact switch. This switch controls the movement of the propeller to any

setting within the flight range. The manual selective control system is entirely separate from the constant speed control, and therefore offers added reliability.

The feathering control is a toggle switch which opens the normal propeller circuit and simultaneously closes the circuit to the feathering



Courtesy Curtiss Propeller

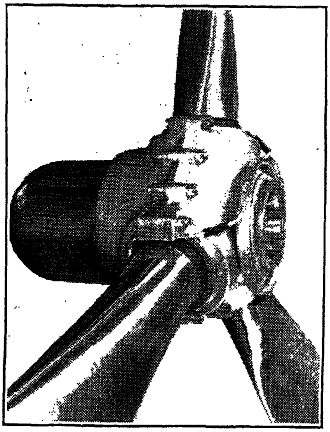
FIG. 218. Schematic diagram of Curtiss proportional governor.

limit switch in the propeller. The blades will then assume the feather setting at which point the current is cut off by the opening of the limit switch.

De-Icing of Propellers. The formation of ice on any part of an aircraft is objectionable. Under some weather conditions it cannot be prevented from forming, but it can be removed as it is formed. If

large sections of ice are allowed to form on a propeller they may cause damage to the airplane as they break from the propeller. This is especially true of a multiengined plane which has parts of the airplane in the plane of rotation of the propeller.

A controllable pitch propeller which has an external pitch-changing mechanism may be made inoperative, as far as pitch changing is concerned, by the formation of ice in the mechanism. Such propellers usually have the exposed portion of the pitch-changing mechanism covered by a spinner to shield the mechanism.



Courtesy Hamilton Standard Propellers

FIG. 219. De-icer fluid slinger ring assembly installed on Hydromatic propeller.

The general practice for removing ice from the blades is to cover them with a film of some mixture which will prevent the ice from sticking as it is formed. A mixture of glycerine and alcohol is generally used for this purpose. The mixture is distributed to the blades through a slinger ring which distributes it to the most advantageous point on the root of each blade. Centrifugal force carries the mixture out the blade. Fig. 219 shows the installation of a slinger ring on a Hydromatic propeller. De-icer fluid is pumped to the propeller either manually or mechanically. A continuous flow of fluid should be maintained during icing conditions. Unless there is fluid on the blade as ice begins to form, it is very hard to dispel the ice.

MAINTENANCE

Periodic Inspection and Repair of Wooden Propellers. Before each flight wooden propellers should be inspected for cracks, cuts, separation of laminations, and condition of tips. Special attention should be given to the face of the blades. The security of the mounting should be checked. At periodic intervals of flying time a more thorough inspection of the propeller should be made for such defects as cracks, bruises, scars, warp, oversized holes in the hub, evidence of separated laminations, sections broken off, and defects in the finish. The tipping should be inspected for looseness or slipping, separation of the soldered joints, loose screws or rivets, breaks, cracks, eroded sections and corrosion.

Civil Air Regulations state that wooden propellers damaged to the following extent shall be scrapped:

1. A crack or deep cut across the grain of the wood.
2. A comparatively long, wide, or deep cut parallel to the grain of the wood.
3. A separated lamination.
4. An excess number of screw or nut holes.
5. An appreciable warp.
6. An oversized hub or bolt hole.
7. An appreciable portion of wood missing.

Small cracks parallel to the grain of the wood may be repaired. Appreciable dents or scars which have rough surfaces or shapes that will hold a filler and will not induce failure may be repaired. The details of repair, refinishing, and balancing of wooden propellers are well covered in the latest issue (June, 1941) of the Civil Aeronautics Administration's *Repair and Alteration Manual No. 18.*

Metal Propeller Service. Either daily or before each flight an inspection should be made of the hub and blades as mounted on the airplane. Hubs should be inspected carefully for cracks. Cracks in the hub are most likely to occur at the blade-retaining shoulders just at the parting line between the front and rear halves of the hub. The blades, especially the leading edges and the faces, should be inspected for scars, dents, and erosion.

At intervals corresponding approximately to 50 hr of flying time, a close visual inspection of the propeller blades, hub, and all propeller accessories should be made. Counterweight-type propellers should be inspected for security of all attaching bolts, clevises, cotter pins, and other locking devices. The cylinder assembly should be checked for oil leakage. The exposed portion of the piston should be cleaned with engine oil. This can be done with the propeller in the low pitch position. After the engine has been warmed up, the cockpit control should be operated to check the pitch-changing mechanism. Governors should be inspected for security of mounting, the condition of tube and fitting connections, and the operation and condition of the control mechanism. If spinners or de-icing equipment are installed they should be inspected for cracks, defects, and rigidity of installation, and care should be taken to see that no parts of these assemblies contact or rub the blades.

Electrically operated propellers should have the complete electrical circuit checked. The brushes should be inspected for wear, and all oil and foreign matter should be cleaned from the brushes and brush holders. The tension of the brush spring should be checked and the

slip rings cleaned. The electrical circuit through the brushes should be checked. The relay points should be inspected for pitting and points dressed if necessary. The operation of the brake and the operation of the limit switches should be checked.

The lubrication requirements of the different propellers vary. Frequency of lubrication periods will also be affected by service and operating conditions. The counterweight-type propellers will require the most frequent lubrication since there is a centrifugal force tending to throw the grease from the counterweights. The lubrication requirements of the counterweight bearing assemblies will be dictated by the frequency of lubrication necessary to maintain smooth pitch-changing operation. The lubrication interval should be approximately 10 hr. To prevent excessive loss of lubricant in the counterweight bearings it is common practice to use a heavier grease for summer operation than for winter operation. Mobilgrease No. 2 and Mobilgrease No. 3 or their equivalents are the two grades usually used.

Mobilgrease No. 2, Intava Grease "A," or the equivalent, should be used in the blade bushings. If the bushings have been thoroughly filled with grease at assembly, very little zerking is necessary between overhaul periods, as the leather grease retainers prevent any grease being thrown from the propeller. It is recommended that propellers be checked every 50 hr with the zerk gun to make certain that the blade cavities are completely filled.

With some operators, it has been an established practice to zerk each blade until grease shows around the shim plates. Grease retainers, however, prevent grease from reaching the shim plates, and this practice cannot be followed with propellers equipped with grease retainers. Excessive zerking may cause the blade plugs to buckle under the pressure, allowing grease to flow out into the hollow portion of the blades and causing unbalance.

If a counterweight-type propeller continues to operate roughly and unevenly after proper lubrication, the counterweight bearing assemblies should be dismantled and inspected.

The manufacturer of the Curtiss electric propeller recommends that the propeller hub assembly be filled with Mobilgrease No. 2 at 100-hr intervals to provide satisfactory lubrication.

The speed reducer oil level should be checked at 100-hr intervals. To accomplish this, the propeller is rotated until the ⅛-in. pipe plug, located in the front housing, is approximately 20 deg below the horizontal plane. The plug opening then indicates the recommended oil level in the speed reducer housing. The normal capacity of this unit is one pint, and only Curtiss Speed Reducer Oil Type No. 1 should be

used. This oil has a very low freezing point; therefore, common lubricating oil should not be used as a substitute.

No other manual lubrication is necessary unless the flexible-shaft type of governor is used; in this event it will be necessary to lubricate the flexible shaft and governor drive adapter at 100-hr intervals.

Since the complete operating mechanism of the Hydromatic propeller is continually surrounded by engine lubricating oil, it needs no other lubrication.

When propellers with aluminum alloy blades are operated over salt water, the salt collecting on the blades tends to oxidize the aluminum alloy. The aluminum oxide formed is a white powder, which is not in itself harmful, but it should be removed and the blades protected to prevent further formation. Rubbing the blades with a rag saturated with "used" engine oil is a very good method of both removing the aluminum oxide and protecting the blade. The carbon in the oil acts as a mild abrasive and the film of oil left on the blades protects them against further corrosion.

Some blades are given an anodic treatment or may be treated with a clear lacquer for protection against corrosion. This protection is not very permanent on working surfaces, such as the leading edge of the blade, but it is usually ample protection for the remaining portion of the blade and reduces the amount of care required and generally confines to the leading edge any reworking required to remove corrosion.

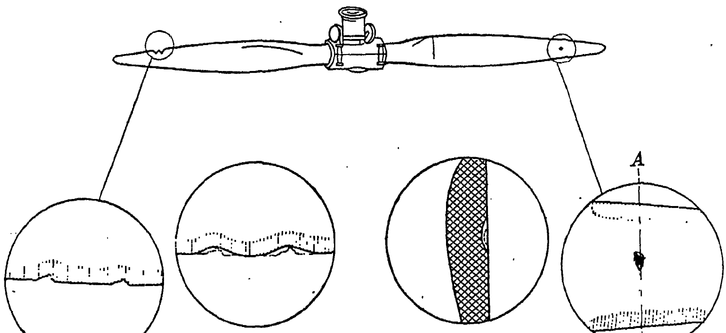
When airplanes land and take off on water there is a certain amount of water spray which propeller blades encounter. The blades contact the particles of water at a high rate of speed and pitting and erosion of the blade faces and leading edges result. If the pits are not removed from the blades they will continue to enlarge through continued erosion and corrosion. For airplanes landing and taking off on water, it is good practice to rub the blades down, first with crocus cloth, and then with used engine oil after each flight. If the pits cannot be removed with crocus cloth it will be necessary to use both emery and crocus cloth. In cases of excessive pitting it will be necessary to smooth the rough edges down with a fine file before using the emery and crocus cloth.

Steel propeller blades resist erosion and abrasion much better than aluminum alloy blades. If they are kept well protected against corrosion by a film of oil they will retain a smooth finish for a considerable time.

Nicks and sharp dents on the leading edges or cuts or gashes on the blade faces are particularly dangerous because they greatly reduce the fatigue strength at that particular point. A failure may result if they

are not removed promptly. All mars on the surfaces of the blades are " stress raisers " and cause a stress concentration which may raise the stress beyond the endurance limit, resulting in a fatigue failure.

Sharp dents and nicks or gashes in aluminum alloy blades may be removed locally without the necessity for reworking the entire blade surface (Fig. 220). A curved or " riffle " file is recommended for use in removing the sharp base of the nick. Fine emery cloth or crocus



Courtesy Hamilton Standard Propellers

FIG. 220. Sketch of typical nicks and method of repair.

should be used for polishing. Care should be taken in removing nicks from the blade face to insure that the thickness is not reduced more than is necessary. After removal of a nick or dent the surface should be etched (as will be explained later), and examined with a magnifying glass, of from two to four powers, to insure that the nick or dent is entirely removed and that a crack has not started. If no crack is evident, the surface should then be locally polished. The maximum reduction in blade thickness and width allowed by Civil Air Regulations when making repairs as above is shown in Fig. 224.

Because of the high surface hardness of steel blades, nicks, scars, and stone bruises on a steel blade will be relatively small as compared to those on the aluminum alloy blades. Raised edges of scars or scratches may be dressed off by hand stoning. A blade developing a crack of any nature should be returned to the manufacturer.

Counterweight-Type Propeller Operating Troubles and Remedies. The following troubles, causes, and remedies are applicable to the counterweight-type propeller:

1. *Oil leaks.* The following gaskets may need attention:
   a. Cylinder head gasket. If this is leaking the cylinder will be covered with oil and oil may drip from the cylinder head after the propeller stops whirling. The cylinder head may not have been tightened sufficiently to compress the gasket into an oiltight seal, or the gasket may have been damaged and may need replacing.
   b. Inboard and outboard piston gaskets. If the leak is here, there will be oil at the base of the cylinder and on the barrel. The piston gasket nut may be loose or the gaskets may be worn. The outboard gasket usually needs replacement more frequently than the inboard gasket.
   c. The piston oil seal. If the leak is here, oil will come out breather holes in the base of the piston. Tighten oil seal nut or replace the oil seal.
   d. The front cone packing washer (only 12D40 and 2D30 propellers for engines not having crankshaft ventilation). This leak will show oil at the base of the barrel. The packing must be replaced. In turning the piston on the crankshaft, this gasket is sometimes caught on the crankshaft threads and torn.
2. *Grease throwing.* This should be rare with the grease retainers. If it occurs it is likely to be due to:
   a. Accidentally pumping grease in the barrel while zerking.
   b. Excess grease being thrown from the counterweights. In both of these cases, the throwing should stop after the first flight or run-up. The grease will be thrown out in gobs. The blades will not be coated evenly with it.
   c. A grease retainer which is not functioning properly. Grease will form a coating over the blade shank. The remedy is to change the grease retainer.
3. *Sluggish pitch change.*
   a. Check to see that the cockpit control is functioning correctly.
   b. Low oil pressure. Check this as near the engine transfer rings as is practicable. The constant speed control unit should deliver between 180 to 200 lb per sq in. For controllable-propeller operation, the pressure should be not less than 60 lb.
   c. Counterweight bearing trouble. Inspect retainers and races for damage. See that cap races are installed correctly and that clearance between counterweight brackets and cylinder is neither too tight nor too loose.
   d. Insufficient hub lubrication. Make sure hub spider arms are full of grease. Check each Alemite fitting (one for each blade) with the zerk gun.
   e. Excessive leakage at engine transfer rings. This is indicated when oil pressure is correct (see *b* above) and propeller shifts normally from low toward high pitch but is slow in changing from high toward low. The condition usually becomes worse when engine oil warms up.

Installation and Removal of the Fixed-Pitch Propeller. Although the engine mechanic may seldom be charged with the overhaul of propellers, he may often have the task of installing or removing a propeller. It is felt that, because of the number of mechanics who will be confronted with this task, it will be worth while to include in this chapter detailed instructions for the installation and removal of the most widely used propellers.

The use of the splined shaft is the most universal method for attaching the propeller to the engine. Splines, milled on the crankshaft of direct drive engines or on a short shaft, known as the propeller shaft on geared engines, mesh with splines broached on the inside of the propeller hub. The splines carry all the torque load but do no centering. Centering is accomplished by two cones placed on the shaft, one on each end of the hub.

Proper installation of metal propellers is highly important if satisfactory operating conditions are to be obtained.

INSTALLATION

1. Hub cones and seats should be carefully inspected to insure firm contact. If *galled,* the marks or high spots should be removed by use of fine emery cloth, or the cone should be replaced.

2. Front cones should be inspected to insure that the halves are matched by number.

3. Light oil, or preferably a corrosion preventive, such as par-al-ketone, should be applied to the cone seats, propeller shaft, and hub splines before installation. Place the rear cone on the propeller shaft. Apply thread lubricant to both the shaft and retainer nut threads.

4. Assemble the front cone halves, the nut, and the snap ring in the hub.

5. Some propeller shafts are provided with one spline wider than the others. There is a mating wide spline groove in the propeller hub which allows the propeller to be installed in only one position with relation to the propeller shaft. Match the wide spline and groove and slide the propeller onto the shaft. Use care not to burr any threads or splines.

6. Push the propeller onto the shaft until the retaining nut engages the threads on the propeller shaft. To assure correct threading, the nut should be turned by hand for the first few threads. Pass a steel bar through the holes in the nut sleeve and tighten. A support, such as a stepladder, should be placed under the propeller while in a horizontal position to prevent rotation as the nut is being tightened. The force exerted by one man using a bar 2 or 3 ft in length is considered ample to tighten hub retaining nuts properly, if the cones are properly seated.

Propellers with rear extension hubs may be checked for the proper installation tightness as follows. With a set of micrometers measure the outside diameter of the propeller hub over the rear extension cone seat at two diameters

approximately 90 degrees apart, before the hub retaining nut is tightened. Mark the points of measurement with a lead pencil. After the hub nut has been tightened, measure the diameters again at the same points. If the propeller is installed properly, the stretch of the rear cone seat should be sufficient to have increased the diameter from 0.002 to 0.004 in.

7. Lock the retaining nut in place by installing the clevis pin through the matching holes in the propeller shaft and retaining nut sleeve. The clevis pin is always installed with the head to the inside. Safety the clevis pin with a cotter pin.

8. After installation, the propeller should be rotated and the track checked. If the error in track exceeds ⅛ in., the propeller should be removed, checked, and corrected.

9. After test flight, the hub retaining nut should be checked for tightness.

REMOVAL

1. Remove the clevis pin and loosen the retaining nut by means of the steel bar. The propeller should be supported, as during installation, to prevent rotation. If difficulty is encountered in loosening the nut, a blow with a hammer at about the middle of the wrench handle, while force is being applied at the end of the handle, will usually break the nut loose.

2. The retaining nut, front cone halves, and snap ring act as a puller as the nut is unscrewed. As the nut is unscrewed it draws the cone halves with it. The cone halves shoulder against the snap ring, thereby pulling the hub out as the nut is unscrewed. After the nut is free the propeller may be removed from the shaft. Care must be taken to prevent galling of the shaft threads and splines. Adequate means of supporting the propeller as it is removed must be provided.

Installation and Removal of Hamilton Standard Counterweight-Type Propellers. The following instructions cover the installation and removal of Hamilton Standard counterweight-type propellers, Models 3E50 (10 deg), 3E50 (20 deg), 3D40 (10 deg), 3D40 (15 deg), 3D40 (20 deg), 2E40 (10 deg) and 2E40 (20 deg). The reference to springs is irrelevant to those propellers not having springs.

INSTALLATION

1. Remove the screw plug from the propeller oil feed line inside the crankshaft.

2. Install the correct engine shaft oil plug or oil supply pipe.

3. Dress off all corrosion, galling, scores, and scratches on the crankshaft and install bronze rear cone on the engine shaft, against the thrust nut.

4. Install split front cone on the propeller piston. It is recommended that the cylinder and piston be removed from the propeller for this installation. This is because the front cone cannot be installed without moving the cylinder out toward low pitch. Also any movement of the cylinder, before the piston

is screwed on the crankshaft, tends to cock the assembly, thereby making it difficult to start the piston on the crankshaft and possibly causing damage to the crankshaft threads.

The cylinder and piston are removed by unscrewing the counterweight caps, taking the adjusting screws out of the cams in the counterweights, removing the counterweights, and unscrewing the counterweight bearing shafts. Be careful, in removing the adjusting screws, not to disturb the position of the nuts.

5. Oil the crankshaft and rear cone.

6. Put the propeller on the crankshaft.

7. Oil the front cone and the piston threads.

8. Assemble the cylinder, piston, snap ring, and front cone. When placing this assembly on the crankshaft, be sure that the numbers above the cylinder bearing shaft bushings correspond to the adjacent counterweight brackets.

9. Screw the piston on the crankshaft. Make sure that the piston and crankshaft threads are in perfect alignment. In no case should force be used to tighten the piston if there is binding or indication that the threads are not properly started; otherwise, serious damage may result. As the piston is turned on the crankshaft, the oil supply pipe in the engine shaft is forced through the gasket at the base of the piston.

10. Tighten the piston on the crankshaft. Use the propeller wrench and a bar about 4 ft long. Apply a force of approximately 180 lb at the end of the bar.

To insure the piston being pulled home, the bar should be rapped once on the section next to the wrench. Use a normal swing with not more than a 2½-pound hammer. This should be done while the force is being exerted at the end of the bar. This operation should be repeated after the first flight and a check should be made at the end of 25 to 50 hr to see that the piston is tight.

Caution: Do not in any event attempt to tighten the piston by hammering on the *end* of the bar.

11. Snap the snap ring in place.

12. Install the two piston gaskets; the one having the longer flange is the inboard gasket.

13. Install the counterweight bearing shaft thrust bearing assemblies in the cups of the cylinder bearing shaft bushings. This assembly consists of two circular races and a ball thrust retainer. The race with the smaller inside diameter is the inner race and should be installed in the cup first.

14. Place the counterweight bearing races, retainers, and cap races in the brackets. Slip the circular Oilite washers between the outer race of the cylinder bearing shaft thrust bearing assemblies and the arm of the brackets. Screw the bearing shafts in their correspondingly numbered holes. It is essential that the grooves in the counterweight races and the bearings in the counterweight retainer match. The curvature of this bearing is gradual. To make positive that the cap races are not assembled upside down, an arc is stamped on the outer face, indicating the direction of the bend in the

grooves. After the bearing shaft has been screwed up tight, this arc should be checked.

15. Lock the bearing shafts in the cylinder with the bearing shaft clevis pins, and cotter the pins.

16. Slip the spacers into place in the counterweight bracket slots, and assemble the counterweights, making sure that the number of each corresponds to its bracket.

17. Insert the complete spring assembly in the piston and tighten the piston gasket nut. Use a bar approximately 2 ft long.

18. Place the cylinder head gasket on the cylinder head. A light coating of grease will hold this gasket in place.

19. Screw the cylinder head on the cylinder. This should be tightened with the bar used on the piston gasket nut. As the cylinder head is tightened, the clamp washer on the splined spring puller bolt will enter the guide on the under side of the cylinder head. The purpose of this guide is to help center the puller bolt.

20. Lock the cylinder head with its lock ring.

21. Lock the cylinder head to the spring puller bolt by means of the vernier lock plate. By turning the vernier one cog at a time, a combination will be found which will allow the vernier to be pushed into place. The groove and ring on one side of the vernier are to facilitate its removal and should be toward the front.

22. Put clamp nut gasket in place on the cylinder head.

23. Tighten the clamp nut on the threaded end of the spring puller bolt. A relatively short wrench should be used. The object is merely to hold the clamp washer on the spring puller bolt tightly against the cylinder head, and provide an oil seal.

24. Lock the clamp nut with its lock wire.

25. Place the adjusting screws in the counterweights. Be careful not to disturb the adjusting nuts. The cylinder may be removed approximately 8 deg from the basic index setting before the springs become effective. If the high pitch setting is more than 3 deg from the base setting, the propeller should be reindexed.

26. Screw on the counterweight caps, making sure that the numbers on each correspond with its bracket.

27. Put in the counterweight cap clevis pins and cotters.

28. Check all lock wires and cotters.

Removal

1. Move the blades toward the full high pitch position until the pitch is within 8 deg of the basic index setting of the propeller. This is done to remove all compression from the springs.

Be sure, however, that the blades are not more than 8 degrees away from the base setting or else the springs will be under compression and the threads of the clamp nut may be stripped when it is unscrewed.

2. Remove the clamp nut lock ring and unscrew the clamp nut.

3. Remove the vernier lock plate and the clamp nut gasket. Failure to remove the vernier lock plate before attempting to unscrew the cylinder head will result in serious damage to the puller bolt.

4. Remove the cylinder head lock ring and unscrew the cylinder head.

5. Unscrew the piston gasket nut and take out the spring assembly.

6. Remove the two piston gaskets.

7. Unscrew the piston.

8. Remove the propeller from the crankshaft. Take care not to damage the engine shaft threads.

The following installation and removal instructions cover Hamilton Standard counterweight-type propellers Models 12D40 (10 deg and 15 deg), 2D30 (10 deg and 15 deg), and 2B20 (8 deg and 15 deg).

INSTALLATION

1. Inspect and clean the cone seat, engine shaft, and rear cone.
2. Clean out the inside of the crankshaft.
3. Remove the screw plug from inside the crankshaft.
   a. On Wright engines, screw the oil supply pipe in the oil plug hole which is located inside the crankshaft.
   (Some models require a gasket under the oil supply pipe.)
4. Locate the rear cone on the engine shaft against the thrust nut or spacer.
5. Remove the propeller cylinder head lock wire and unscrew the cylinder head.
   a. On propellers for Wright engines remove the piston gasket nut, breather pipe packing nut, and packing. The piston gaskets will now be loose and should be removed in order to prevent damaging.
   b. The piston gaskets may be left in place on other engine installations.

6. Place the propeller on the crankshaft. Make sure that the piston and crankshaft threads are in perfect alignment. In no case should force be used to tighten the piston if there is binding or indication that the threads are not properly started, otherwise serious damage may result. Where it is found that, owing to handling or reassembly without proper adapters, the piston and shaft are not in alignment, the counterweights should be disassembled and the bearing shafts removed. This frees the cylinder and piston to permit easy starting of the threads and proper tightening of the propeller on the shaft. The counterweights may then be reassembled. Care should be taken in tightening the piston to see that the front cone packing washer, when one is required, does not bind, but is pulled properly into place. (Wright engines do not require packing washers.) As an aid in assembly, it is suggested that the piston be tightened a few turns and then the hub jarred slightly by hand. This will help prevent jamming the washer on the shaft threads.

7. Tighten the piston by using a bar approximately 4 ft long. Apply a force at the end of the bar of about 180 lb. To insure the piston being pulled home, the bar should be rapped once on the section next to the wrench. Use a normal swing with not more than a 2½-lb hammer. This should be done while

the force is being exerted at the end of the bar. This operation should be repeated after the first flight and a check made at the end of 25 to 50 hr to see that the piston is tight.

Caution: Do not, in any event, attempt to tighten the piston by hammering on the *end* of the bar.

8. Secure the piston with the lock ring. Cotter the lock ring. Use steel cotter pins, 2 or 3 as required.
9. On propellers for Wright engines, install the piston gasket nut and cotter.
   a. On other engine installations, check to see that piston gasket nut is cottered.
   b. On propellers for Wright engines, put the breather pipe packing and packing nut in place. Tighten the packing nut and secure it with lock wire.
10. Install the cylinder head and the cylinder head gasket, and be sure that the gasket rests squarely on the cylinder head. The gasket may be held in place with grease.
11. Tighten the cylinder head.
12. Secure the cylinder head with its lock wire.
13. Check all cotters and lock wires.

REMOVAL

1. Disengage the cylinder head lock wire and remove the cylinder head. Have a pail handy to catch the oil which will be in the cylinder.

Note: On Wright engines, loosen the oil supply pipe packing nut and unscrew the piston gasket nut.

2. Disengage the piston lock ring by removing the cotter pins. It is good practice to slide the lock ring up on the piston and safety it there.
3. Unscrew the piston. This will start the propeller off the engine shaft.
4. Slide the propeller slowly forward on the engine shaft and remove. Take care not to damage the engine shaft threads. On Wright engines care must be taken not to hit the oil supply pipe.

Installation and Removal of Hamilton Standard Hydromatic Propellers. The following instructions cover the installation and removal of Hamilton Standard Hydromatic propellers, 23E50–31 and above. The wrench numbers referred to are Hamilton Standard tool part numbers.

The Hydromatic propeller, as prepared for installation on the engine shaft, consists of three subassemblies: the hub and blade assembly, which includes the hub retaining nut and front cone, the distributor valve assembly, and the dome assembly.

Prior to installation, each subassembly should be carefully inspected for cleanliness.

Wherever possible, the subassemblies and hub attaching parts for each propeller should be kept together as a complete assembly.

The distributor valve assemblies of the same type are interchangeable.

Dome assemblies are interchangeable if checked with the hub assembly for balance and gear preload.

INSTALLATION

1. Coat the engine shaft and cones with engine oil and install the propeller barrel and blade assembly on the propeller shaft. Slide it back only far enough at first to engage the threads of the propeller retaining nut with those of the shaft.

2. Tighten the propeller retaining nut on the shaft. Use the tubular wrench No. 53004 together with wrench No. 52829 and a bar about 3 ft long. Apply a force of approximately 180 lb at the end of the bar and, while this force is being maintained, rap the bar close to the wrench with a hammer weighing about 2½ lb.

Determine if one of the locking slots in the nut is in alignment with one of the holes in the propeller shaft. If not, repeat the tightening procedure until one slot and one hole are in alignment. Spacing of the slots in the nut is such that alignment of a slot and hole will occur each 5 degrees of rotation.

3. Check to be sure that the 1/32-in. copper gasket (provided by the engine manufacturer) is in place against the adapter flange inside the propeller shaft.

4. Check the valve housing oil transfer plate on the base of the distributor valve assembly to be sure that it is properly in place with the 1/32-in. copper gasket between it and the valve housing.

The oil transfer plate, for use with engines which breathe through the propeller shaft, has a 1¼-in. hole through its center to allow engine breathing. On the plate for use with engines which do not breathe through the shaft, the hole in the center does not go through the plate but connects with the dome oil pressure line in the side of the valve housing.

5. Oil threads of the valve assembly, screw it into the shaft, and tighten it with wrench No. 52829, with the help of a bar about 1 ft long. Apply a force of approximately 100 lb at the end of the bar and, while this force is being maintained, strike the bar near the wrench one light blow with a hammer weighing not more than 2½ lb. If the locking slots in the valve housing are not aligned with the holes in the propeller shaft, repeat this tightening operation until the slots and holes are in alignment.

Caution: Under no conditions should the valve housing be backed off even slightly in order to obtain slot and hole alignments. If alignment cannot be obtained, a new gasket should be used or the original gasket should be lapped slightly.

6. Install the locking ring with the pin through the retaining nut slot and propeller shaft hole and into the valve housing slot. Snap the wire into position in the groove provided for it in the retaining nut.

On propellers for engines which breathe through the propeller shaft, the breather tube is installed on the distributor valve assembly. If, for any reason, this breather tube has been removed, check it to be sure that it is screwed tightly to the distributor valve housing and safetied with a brass

wire through a slot in the skirt of the breather and the hole drilled into the dome pressure duct in the valve housing.

7. Before installing the dome assembly on the propeller, the low pitch limit and high pitch limit adjustments should be made.

This is accomplished by setting the low and high pitch stops to the respective positions desired.

8. On propellers which breathe through the propeller shaft, remove the breather cup lock wire, unscrew the breather cup, and remove the seal from the front end of the dome assembly.

9. Make certain that the dome and barrel oil seal are properly installed around the stationary cam base against the dome.

Caution: When installing the dome assembly, it is ABSOLUTELY ESSENTIAL that the cam gear in the dome be meshed with the blade gear segments in the proper angular relationship and the following steps should be carried out to insure correct meshing.

10. Move the piston in the dome assembly into the extreme forward position. This position will be reached when the cam gear stop lugs are against the high pitch stop lugs.

11. Turn each blade to the high pitch position against the stop pins.

12. Slide the dome assembly over the end of the valve assembly, and make sure that the oil seal rings on the valve assembly enter properly into the sleeve inside the piston. Turn the dome in a counterclockwise direction until the dowels in the barrel dome shelf engage the aligning holes in the stop locating plate. (The dome unit should be installed in the position indicated by markings.) The cam gear and blade gears are now in proper alignment and the dome assembly should be moved, without turning, into the barrel until the dome retaining nut can be started in the threads in the barrel.

On engines which breathe through the propeller shaft, make sure that the breather tube on the front end of the valve assembly is properly started in the hole in the front end of the dome.

The turning of the dome assembly in a clockwise direction in order to align the dowels and holes should be avoided, as this will tend to move the stop lugs on the rotating cam away from the high pitch position, thus allowing the gears to mesh incorrectly.

In some instances, depending on the blade design, it is necessary to limit the full-feathering blade angle to slightly more or less than 90 deg (at the 42-in. station) in order to eliminate any tendency of the propeller to windmill forward or backward when feathered. Propellers, in these instances, are provided with stop pins which limit the blade angle to other than 90 deg.

Tighten the dome retaining nut, using wrench No. 52829, in the manner indicated for tightening the propeller retaining nut by applying a force of approximately 180 lb at approximately a 4-ft radius. With the dome assembly properly seated in the barrel, the front face of the dome retaining nut will be approximately flush with the front edge of the barrel.

It is essential that the dome unit be firmly seated on the retaining shoulder in the barrel. Tightening of the dome retaining nut, in addition to fastening

the dome unit to the hub, serves to apply the preloading force to the gears and to compress the dome and barrel seal. Its tightening, therefore, requires a relatively high wrench torque, as indicated above. Failure to tighten the dome unit securely in the hub will result in elongation or failure of the assembly screws which fasten the dome cylinder and the stop locating plate to the stationary cam.

13. Install the dome retaining nut lock screw and safety the screw with a 1/16- by 1/2-in. steel cotter pin.

14. On engines which do not breathe through the propeller shaft, make sure that the dome breather hole nut in the front of the dome is tight and that the lock wire is in place.

On engines which breathe through the propeller shaft, insert the gasket between the breather tube and the front end of the dome.

Install the breather cap and safety it with the locking ring provided.

Caution: Using suitable levers to turn the blades, shift the propeller into full low pitch and check all three blade angles by the index lines on the blades and the graduations on the barrel, or with a protractor. These angles should be equal and should agree with the low pitch stop setting.

This check indicates that the correct relationship between the blade gears and the cam gear has been obtained.

15. Check all external lock wires and cotter pins.

REMOVAL

The procedure for removing the propeller from the propeller shaft is, in general, the reverse of the installation procedure.

1. For installation on engines which breathe through the propeller shaft, remove the lock ring and breather cup from the front of the dome.

2. Remove the lock screw from the dome retaining nut and unscrew the nut. This nut is attached to the dome and acts as a puller when the nut is unscrewed.

3. Remove the dome assembly.

4. Remove the lock ring from the propeller retaining nut.

5. Unscrew the valve assembly.

6. Unscrew the propeller retaining nut and remove the propeller from the shaft.

Note: The hub snap ring and related parts inside the spider are so arranged that, as the retaining nut is backed off, it pulls the propeller with it until the nut reaches the end of the propeller shaft thread.

Installation and Removal of Curtiss Electric Propellers. The following instructions cover the installation and removal of Curtiss electric propellers.

INSTALLATION

The installation of the Curtiss electric propeller on an engine consists of several simple steps. A brush housing is first attached to the nose of the

engine. The propeller proper is installed on the shaft, with standard front and rear centering cones, in the same manner as the earlier type of fixed-pitch propellers. To tighten the propeller shaft nut a bar 1 in. in diameter is all that is required. A force of approximately 250 lb at the end of a 3-ft bar is enough to tighten satisfactorily the propeller shaft nut. In other words, a torque of 700 to 1000 ft-lb is required. The shaft nut is then locked by a sleeve inside the nut which engages with a pentagonal adapter located in the end of the engine shaft. A spring-loaded locking device engages both the locking sleeve and shaft nut, thereby locking the nut.

It will be desirable to make a check of the location of the brushes with reference to the propeller slip rings. This is accomplished by applying a light coating of Prussian blue on ends of slip ring brushes and placing the brush assembly in the housing. Rotate the propeller back and forth slightly, then remove the brush assembly and check the location of the brush contact on the slip rings as indicated by the Prussian blue. The brush track should be in approximately the center of the rings and not closer than 0.020 in. to the slip ring separators. If the brushes are not correctly aligned, it will be necessary to place one or more stainless steel shims between the rear centering cone and the thrust nut. When alignment is satisfactory, the brushes and slip rings are cleaned and the brush assembly replaced.

The individual propeller blades must then be set to approximately the low pitch setting of the propeller as indicated by the index marks located on the blade shanks.

The power unit must then be checked to determine if it is at its low pitch setting. This can be determined by removing the power gear adapter plate assembly and observing the location of the limit switch cam lobe with respect to the low limit switch cam follower. The limit switch arm should be just riding on the cam lobe. If it is necessary to run the power unit to locate the cam properly, it becomes imperative to remove the steel mechanical low stop plug from the speed reducer housing (to avoid possible damage); then the unit may safely be operated by applying the proper voltage to the contacts on the rear face of the speed reducer. It will be noted that the common or negative contact does not have a limit switch arm. In order to rotate the cam, current will be applied to the common contact and either the increase pitch or decrease pitch contact, whichever is required to locate the cam properly. After replacing the adapter plate assembly, noting that the power gear is properly indexed on the speed reducer spline, attach the power unit to the propeller hub with hexhead bolts. The bolts are then secured with safety wire and the power unit cover is then installed and secured.

Removal

The procedure for removing the propeller from the propeller shaft is, in general, the reverse of the installation procedure. The slip ring brushes must be removed before the propeller to prevent damage.

Overhaul and Repair of Propellers. Propeller overhaul periods will be determined by the type of propeller and the service conditions. Under favorable operating conditions the propeller overhaul period may coincide with the engine overhaul period. Civil Air Regulations specify that the overhaul, repair, or alteration of a certificated propeller shall be made by the manufacturer of the propeller, or made by, or continuously supervised by, a certificated airplane or engine mechanic only. It is recommended, in all instances of overhaul, repair, or alteration of propellers, that the persons to whom such duties are delegated thoroughly acquaint themselves with the applicable service literature of the propeller manufacturer.

In general, overhaul involves the disassembly of the propeller. After a thorough cleaning the parts are inspected visually for wear or damage. All the ferrous parts, such as hub, gears, cams, and bolts, should be inspected for cracks by the Magnaflux method. Particular attention should be given to areas of high local stress, such as the inner corners of hub blade retaining shoulders, gear-teeth roots, and corners under bolt heads, to make certain that cracks have not occurred. Any part which has developed a crack must be rejected.

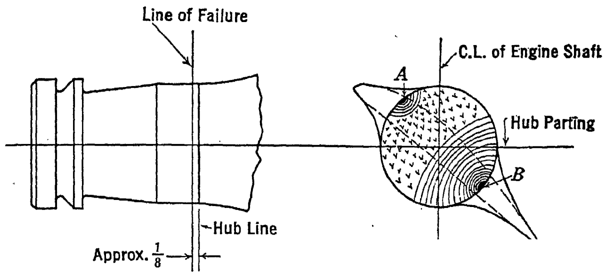
Splines and cone seats should be inspected for wear. Continued use of hubs with excessive spline wear may result in extreme damage to the engine shaft or propeller hub or both. The wear of hub splines may be checked by mounting the hub on a standard, unworn splined shaft and measuring the rotative play. If the rotative play at the spline exceeds 0.005 in. the hub should be rejected. To decrease the error of measurement the rotative play may be measured at a distance from the center of the shaft of, say, 10 times the radius of the spline. At this point the maximum rotative play limit would be 0.005 in. $\times$ 10 = 0.050 in. Special spline gauges may also be used for checking spline wear.

Rear cones may be lapped to secure a satisfactory seat. It is good practice first to lap the cones in a standard bench fixture and then secure satisfactory seating by a final light lapping in the hub. This will prevent excessive removal of metal from the hub and probable distortion of the correct angularity of the seat.

All hub parts should be kept together as an assembly. It is imperative that such mating parts as the front and rear hub halves and the front cone halves be retained together as assemblies. These mating parts are machined as an assembly and are not interchangeable with other similar parts. At assembly one should make certain that these parts are properly mated as they were machined (as identical serial numbers on each half will indicate) and that the mated hub

halves are placed together in their original position (this will be indicated if the identical serial numbers are adjacent at the same parting line). Hubs of the same design are interchangeable on the same engine shaft. Blades of the same design are interchangeable between hub assemblies. When replacing or interchanging blades an effort should be made to mate blades of equal weight which have had about the same service time.

At overhaul periods the propeller blades should be dressed off with sandpaper, emery paper, or wet-or-dry paper to remove nicks, scratches, and the effects of erosion. If the surface of the blades is rough a coarse abrasive may be used first, graduating to finer



Courtesy Hamilton Standard Propellers

FIG. 221. Location of stress concentrations in the propeller blade shank. Failure is most likely to appear in line with stiff section of blade as shown at points A and B.

abrasives. Care should be taken not to remove more metal than is necessary to provide the blades with a smooth finish. After the blades have been given a smooth finish they should be cleaned and inspected for cracks. Critical areas, as the region of the hub rim of the clamp ring location, should be inspected with a magnifying glass, and if there is suspicion of cracks the area should be locally etched.

Blades which have been damaged or which have apparent defects that cannot be fully determined by local etching should be given a general etching. Before etching, all paint should be removed from the blade and it should be thoroughly cleaned. The etching solution should be a 10 to 20 per cent aqueous solution of caustic soda, which consists of 1 to 2 lb of commercial caustic soda for each gallon of water used. For best results the solution should be heated to 160 to 180°F. Swab the section of blade to be inspected until it is well blackened, or immerse in the bath for 15 to 30 sec. After the blade is well blackened rinse immediately in clear water. Then neutralize the caustic action by swabbing with or dipping in a solution composed of 1 part commer-

cial nitric acid to each 10 parts of water. Rinse the blade again with clear water, and then inspect for cracks with a magnifying glass of 2 to 4 powers. Suspected cracks should be given a local etching and again examined.

Small inclusions which form longitudinal lines owing to the forging process are not important, but any cracks or seams across the blade are usually a sign of impending fatigue failure and are cause for rejection.

Care should be exercised not to etch the shank portion of the blades except as recommended, as this would affect the fit in the hub. A light local etch about 2 in. in diameter is permitted on the clamping section

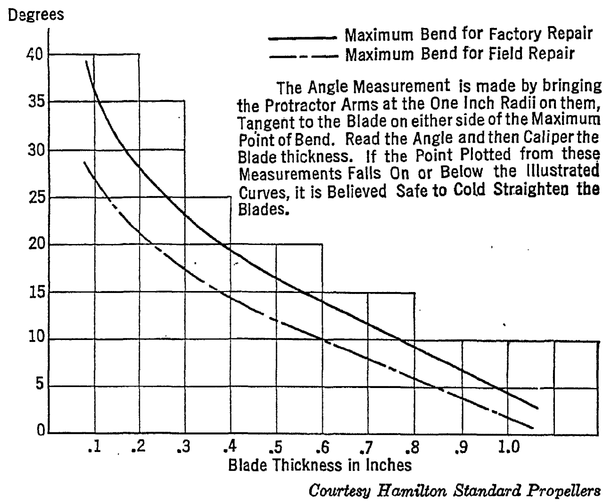


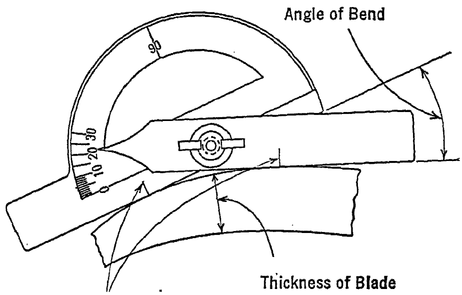
Fig. 222. Maximum angle of bend in length of two inches for straightening aluminum alloy blades without heat treatment.

of the blade shank at the critical points in line with the leading edge and trailing edge of the airfoil section. The shank portions of controllable-pitch blades may be given a light local etch where cracks are suspected. Care should be taken to remove all traces of local etching on the shank section by polishing. Any crack is cause for rejection.

The hub assembly of a damaged propeller must be thoroughly inspected for cracks by the Magnaflux method. Particular attention should be paid to the inside in the region of the blade retaining shoulders. Cracks usually start in line with the leading and trailing edges of the blade. Any indication of a crack is cause for rejection. The

hub should be dimensionally inspected for conformity to the drawing. Twisted or sprung hubs cannot be repaired and must be scrapped.

Blades which have not been bent beyond certain limits and which are not on the "manufacturer's list of blades not approved for repairs which require straightening," may be satisfactorily repaired. The maximum bend, at varying thicknesses of blade section, for field repair by cold straightening is given in Fig. 222. The method of measuring the angle of bend at any point is shown in Fig. 223. Blades with bends slightly greater than those reparable in the field may be repaired by cold straightening at the factory, as shown in Fig. 222. Blades bent too much for cold straightening will require heat treatment and must be returned to the factory for repairs. The allowable reduction in blade width and thickness for repairs is shown in Fig. 224.



Courtesy Hamilton Standard Propellers

FIG. 223. Method of measuring angle of bend in length of two inches of propeller blade.

Assembly of the Propeller. The assembly of propellers other than the adjustable fixed-pitch propeller is beyond the scope of this book. When assembling controllable-pitch propellers the manufacturer's instruction manual should always be consulted.

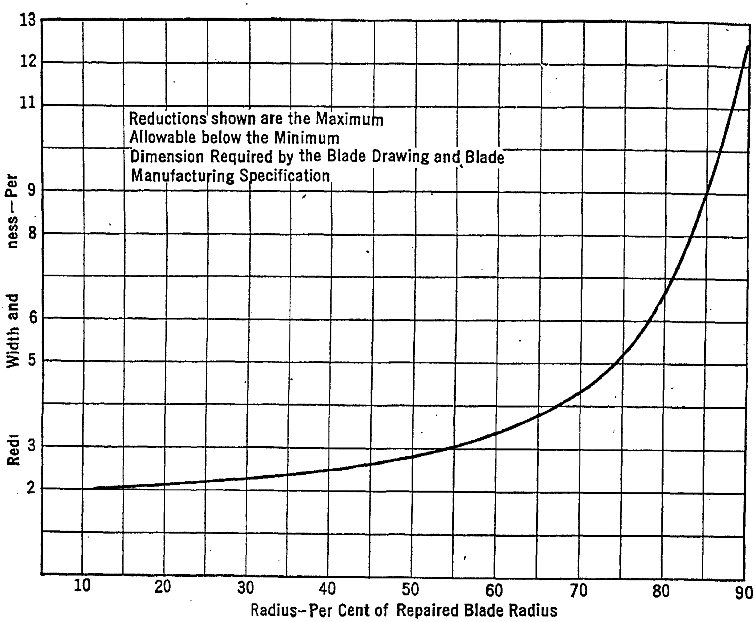
To prevent the inner edges of the hub parting surfaces from cutting into the blade shank when the clamp rings are tightened, it is desirable to have a radius on the inner edge of the parting slot. Early types of hubs were not provided with this radius. If any early type of hub has not been reworked to provide this radius, it should be reworked before assembly to provide a $\frac{1}{16}$-in. radius. A fine-tooth file may be used for the reworking.

After the blade shanks and inner surfaces of the propeller hub have been thoroughly cleaned, they should be coated with a corrosion inhibitor such as par-al-ketone. This will prevent corrosion in the contact regions which, if not carefully guarded against, might lead to fatigue cracks and ultimate failure. Threaded parts should be lubricated with a thread lubricant.

Hub clamp rings should be installed with the bolt to the front. It is not necessarily desirable that the bolt be directly across the parting

line. If the propeller is to be installed on an engine which does not have sufficient clearance for the clevis pin side of the clamp, the clamps may be placed so that the bolt sides are 45 deg to the shaft bore center line and 90 deg apart. Clamp rings should always be installed with the clevis hinge pin head toward the engine shaft.

After the blades and clamp rings have been installed, the clamp rings are moved outward against the shoulders on the end of the hub.



Courtesy Hamilton Standard Propellers

FIG. 224. Repair limits to section width and thickness for aluminum alloy propeller blades.

The clamps are tightened until the blades just turn hard. The hub is installed on the vertical spindle on the propeller setting plane table. The desired pitch angle for the 42-in. (or ¾ radius) station is set on the protractor and the protractor blade is clamped in place. The blades are pulled outward to make sure that the shear shoulders of the blades are up against the hub shoulders. The station on the blade at which the pitch angle is to be set is marked with a lead pencil. A metal scribe should never be used for marking propellers. The protractor is placed under the propeller face. It is essential that the protractor arm be at right angles to the center line of the blade. The blade is rotated in the hub by tapping until the pitch is such that the flat face

of the blade touches the protractor arm all across the blade. The clamp bolt is tightened by using a wrench which does not have more than a 12-in. leverage. After all of the blades have been set each one should be given a final check. A difference of 0.1 deg between blade pitch settings may produce vibration. A difference of 0.3 deg will produce excessive vibration.

For adjustable fixed-pitch propellers the pitch setting should be that which will allow the engine to turn at its rated rpm with full throttle in level flight at its rated altitude. A lower pitch setting than that will give a condition which will favor take-off and climb, but will reduce the cruising and high speed performance. A higher pitch setting will generally improve cruising economy, but will reduce take-off, climb, and high speed performance. A change of from 60 to 90 propeller rpm, while in level flight, with full throttle at rated altitude, will be caused by a 1-deg change in blade angle setting. The change in engine rpm will depend upon the propeller-engine gear ratio.

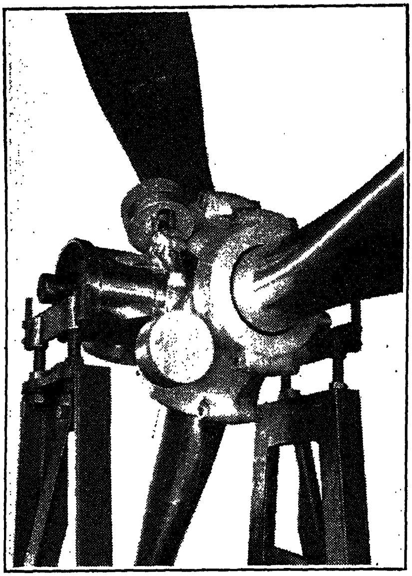
While the propeller is still on the plane table, it should be checked for track. A line has already been drawn across the face of the blades at the 42-in. (or ¾ radius) station. At each 6-in. point from that station to the tip lines are drawn across the face of the blades, 90 deg to the longitudinal center line of the blades. With the inner edge of a square resting against the trailing edge, a point 1 in. forward of the trailing edge is marked off on each of these lines. With a surface gauge the height of each of the points above the plane table is checked. The difference in track of any like points on the blades should not exceed $\frac{1}{16}$ in.

To prevent glare in the pilot's face, the propeller blade faces are generally painted a dull color. To increase the visibility of a revolving propeller and lessen the danger of persons walking into them, both sides of the tips are often painted with stripes of a bright color. Propeller hubs should never be painted as this would prevent proper inspection for cracks and failures.

Balancing. The static balance of a propeller is dependent upon the static moment of the blades, or the weight of the blades times the moment arms to the center of these masses. Therefore, it is the static moment of a blade rather than the absolute weight which is of importance in static balance. Of course, the mass distribution of the hub must also be taken into consideration.

A propeller may be statically balanced and yet be dynamically or aerodynamically out of balance. Even though dynamic balancing is to be accomplished, static balancing is always carried out as an approach.

For static balancing it is necessary to mount the propeller on a knife-edge balancing stand by using a suitable hardened and ground mandrel secured in the exact center line of the hub. The balancing stand must be true and level. The balancing must be done in a room free from air currents. All blades must be set at the same angle. On adjustable fixed-pitch propellers the clamp rings must be against the shoulders on the end of the hub. Balance must never be obtained by moving the clamp rings in toward the center of the hub. Centrifugal force and vibration would soon move the clamp rings outward, throwing the propeller out of balance. Controllable-pitch propellers should be balanced dry, except for the lubrication required in assembly.



Courtesy Hamilton Standard Propellers

FIG. 225. Balancing a three-bladed propeller.

For a two-bladed propeller, the balance is checked first with the propeller in a horizontal position. Then the balance is checked with the propeller in a vertical position. In either position the propeller must show no tendency to rotate.

For a three-bladed propeller each blade should be placed successively in the horizontal and vertical position. In each position there should be no persistent tendency to rotate.

Blades are provided with holes or studs at the butt or inner center end at which lead or washers can be added or deleted to obtain balance. Horizontal balance should be obtained by the addition or deletion of lead from these holes. A piece of putty stuck on the blades at the radial location of the lead holes will indicate the amount of lead to be added or deleted. If possible it is best to delete lead from the heavy blade. After balancing the lead holes should be properly corked or the stud retaining nut securely tightened.

Vertical balance and minor adjustments in horizontal balance may be accomplished on adjustable fixed-pitch propellers by rotation of the clamp rings. On controllable-pitch propellers vertical balance and

minor adjustments in horizontal balance may be accomplished by the addition or deletion of lead in the hollow hub bolts.

Hamilton Standard Constant Speed Control. The Hamilton Standard constant speed control, or governor as it is usually called, is a self-contained unit working in oil and is subjected to little wear. Routine inspections between overhauls require only a visual examination to see that there are no external oil leaks; that the mounting is secure; that the control system is properly installed and safetied and that it is free from lost motion; where external piping is installed, that fittings are tight and not leaking and that the piping is securely mounted so as not to subject it to excessive vibration which might cause failure.

The flyball compartment is provided with a drain which conducts oil entering the compartment back into the engine. Still, oil sometimes leaks from the governor at the control shaft oil seal. This is especially true of installations which utilize rod controls and which subject the oil seal to a hammering because of vibration. Should this oil seal be leaking enough to warrant action, the packing washer should be replaced. One should never try to stop the leakage by tightening up the control shaft packing nut. Tightening this nut has absolutely no effect upon the seal and, since the nut has tapered threads, it will spread and may crack the cover shaft boss. To replace the packing washer it will be necessary to remove the control pulley or control arm, whichever is installed. Before removing the pulley or arm one should revolve the control shaft by means of the cockpit control, so that the speeder spring is extended. One should identify the relation of the control shaft with the pulley or arm so that they may be reinstalled in their original position. This may be done by marking the shaft hex end and pulley after the pulley retaining nut is removed. If the pulley is not reinstalled in its original position it will be necessary to readjust the control system completely.

The overhaul of the governor consists mainly in cleaning the unit. While the unit is disassembled the following parts should be inspected for wear:

1. The pilot valve ball bearing should be cleaned and carefully examined to insure good condition. This part should be replaced if found worn.

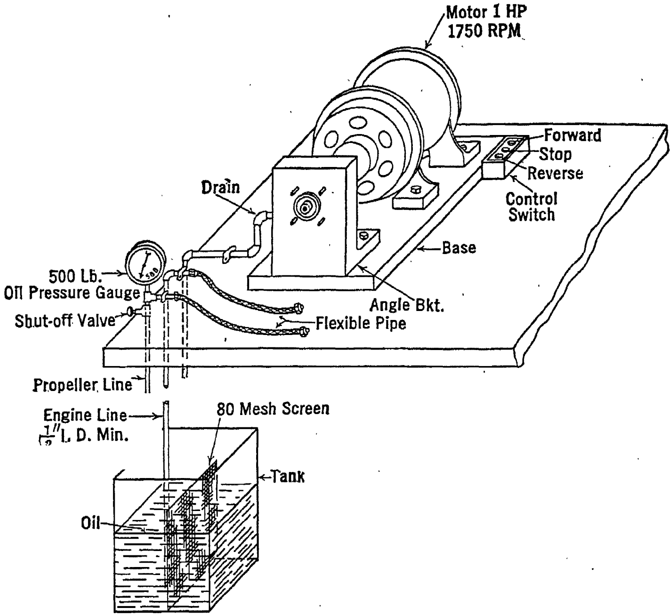
2. The threads on the upper end of the spring collar should be examined to be sure that they have not been worn by the pilot valve nut. If worn, the pilot valve spring collar assembly should be replaced.

3. The spring collar spacer and the oil pressure relief valve plunger should be inspected for indications of scoring. If these units show

signs of being scored they should be polished with fine emery and crocus cloth.

4. The idler gear shaft should be inspected for side wear. If it shows indications of being worn, the shaft should be replaced.

5. The teeth of the control shaft should be inspected for wear. This shaft is plated and the wearing off of the plating should not be confused with actual wearing of the teeth. This shaft should be replaced if the teeth are badly worn.



Courtesy Hamilton Standard Propellers

FIG. 226. Test stand for Hamilton Standard constant speed control unit.

6. The test stand run-up of the unit will check the wear on the gear pump, the fit of the pilot valve in the drive gear shaft, and the oil pressure relief valve assembly.

After assembly, the unit should be tested for proper operation. A satisfactory test stand set-up is illustrated in Fig. 226. For proper operation the control unit should meet the following test stand requirements.

1. The internal leakage, when operating at 1750 rpm and at a pressure between 180 and 200 lb per sq in., does not exceed 20 qt per hr with the governor set in positive low pitch position. For serviced controls 30 qt per hr is permissible.

2. The relief valve is set to maintain a pump pressure of from 180 to 200 lb per sq in. plus oil pressure at the intake side of the booster pump on Hydromatic governors. Model 4B6-3 governors are set to maintain a pump pressure of 280 to 300 lb per sq in. plus oil pressure at the intake side of the pump.

3. There is no external leakage when the pump chamber and oil passages are subjected to a pressure of 400 lb per sq in.

4. The pump capacity is not less than 8 qt per min at 1750 rpm, at a back-pressure of 150 lb per sq in.

5. All the above tests are to be conducted at room temperature, using an oil of approximately S.A.E. No. 10 viscosity.

It is also essential that the unit be carefully checked to insure that there are no external oil leaks. The point at which leaks are most likely to occur is at the joining surfaces of the mounting base and at the control shaft.

After the control unit has been found to be operating properly, it may be calibrated for take-off and minimum governing speed for the engine on which it is to be installed. The angular position of the control shaft at these two governing speeds should be recorded on a tag to be attached to the governor. This information at installation of the control unit will greatly aid in the adjustment of the controls. A test stand similar to the one shown in Fig. 226 may be used for calibrating the control shaft angular position when the control unit is governing at take-off and minimum governing speeds. It will be necessary, however, to have either a variable speed motor or gear arrangement which will permit revolving the governor drive at both the take-off and minimum governing speeds. It must be remembered that the rpm of the control unit is not necessarily the same as the rpm of the engine, but is determined by the engine governor drive ratio.

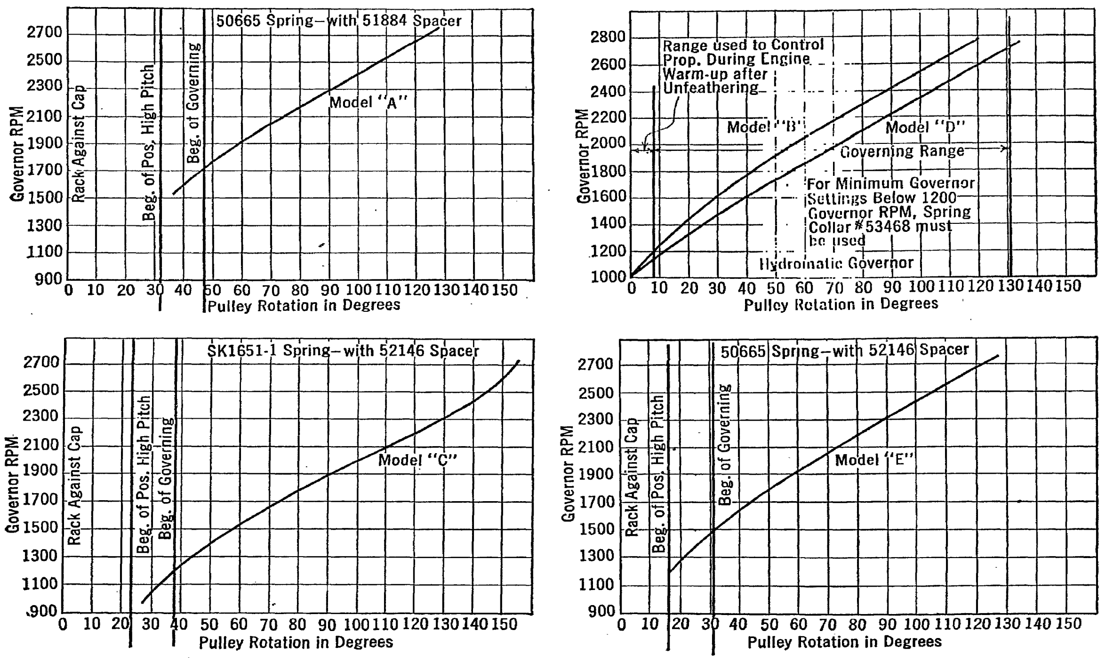
In the event that the control unit is not calibrated on a test stand for the angular position of the control shaft at the take-off and minimum governing speeds, the applicable curve of Fig. 227 will be of aid in adjusting the control unit.

Installation of the Hamilton Standard Constant Speed Control Unit. The following instructions cover the installation and adjustment of the Hamilton Standard constant speed control unit.

INSTALLATION

The clearance between the circular lining boss and the recess in the engine mounting pad should permit an easy fit. The circumference of the circular lining boss may be dressed down to obtain the desired fit.

General freedom between the constant speed control unit drive gear and



Courtesy Hamilton Standard Propellers

FIG. 227. Curves showing pulley rotation vs. governor rpm for several models of Hamilton Standard propeller governors.

the engine drive should be ascertained. This can be done by removing the cover section and rotating the flyball cup assembly to see that the original backlash is maintained as the mounting nuts are tightened. Excessive tightening may damage the gasket or warp the unit's base.

As an additional precaution, turn the engine crankshaft to at least three different positions and check the backlash of the control at these points for free movement.

Installation Adjustments

The angular range required at the constant speed unit to give take-off rpm at one end and minimum governing rpm (positive high pitch on counterweight-type propellers) at the other is only a part of the unit's total angular range. Before flying, it is important that the control system between the constant speed control and the cockpit be adjusted to set the unit for take-off rpm when the cockpit lever is ⅛ in. from its full forward position, and for minimum rpm (positive high pitch on counterweight-type propellers), when the cockpit lever is in its extreme rearward position.

For the trial setting, place the cockpit lever approximately ⅛ in. from the forward end of its full travel. Turn the pulley or lever attached to the constant speed unit's control shaft in a clockwise direction until the rack bottoms in the cover. Rotate the control shaft counterclockwise the necessary number of degrees to give desired take-off rpm in accordance with the applicable curve of Fig. 227. With the control shaft held in this position, connect the linkage between the cockpit control lever and the constant speed control unit. This setting will give approximately the take-off rpm and permit sufficient movement of the cockpit control lever to obtain minimum rpm (positive high pitch on counterweight-type propellers).

The rpm given on the curves of Fig. 227 is that of the constant speed control unit. The rpm of the constant speed unit is determined by the engine drive ratio.

The following are suggested methods of checking and adjusting the trial installation setting. In each case, the purpose is to have the cockpit lever ⅛ in. from its full forward position when the constant speed control unit is set to govern for rated rpm. It should be clearly borne in mind that, with the constant speed control governing, the pilot can only regulate engine rpm and not blade pitch. The only exception to this is positive high pitch (on the counterweight-type propeller only).

Ground Test

Where the low pitch stops in the propeller counterweights have been set to give a low enough blade pitch to permit the engine to turn its take-off rpm or slightly more, at a rated manifold pressure on the blocks, the following procedure applies.

1. If, with the cockpit control full forward, more than take-off rpm is obtained at run-up, the propeller is in full low pitch and the constant speed control is set to governing at higher than take-off rpm. To adjust correctly

the linkage system between the cockpit lever and the constant speed unit, follow the procedure outlined below:

Pull the cockpit lever slowly back until the tachometer indicates a drop in rpm. At this point, the constant speed unit is set to govern at the indicated rpm. Move the cockpit lever forward slightly so that the tachometer reads take-off rpm and shut down the engine. Without disturbing the cockpit lever regulate the adjustable stop at the constant speed unit to limit the rotation of the control shaft to this exact angular position. Readjust the linkage system so that the cockpit lever is within ⅛ in. of its full forward position when the constant speed control pulley or lever is held against the adjustable stop. Minor adjustments may be necessary after flight tests.

2. If, with the cockpit control full forward, the take-off rpm is not obtained at run-up, it is because the constant speed unit is governing at an rpm lower than rated. The blades are not in full low, but are being governed to some higher pitch by the constant speed control. (Loss of engine power may give a similar indication and should be considered.)

Take-off rpm will be obtained when the constant speed control is adjusted to govern at rated rpm. To accomplish this, stop the engine and readjust the linkage system with the constant speed unit's pulley or lever rotated in a counterclockwise direction. When take-off rpm is obtained at rated manifold pressure, proceed as outlined above under 1.

Flight Test

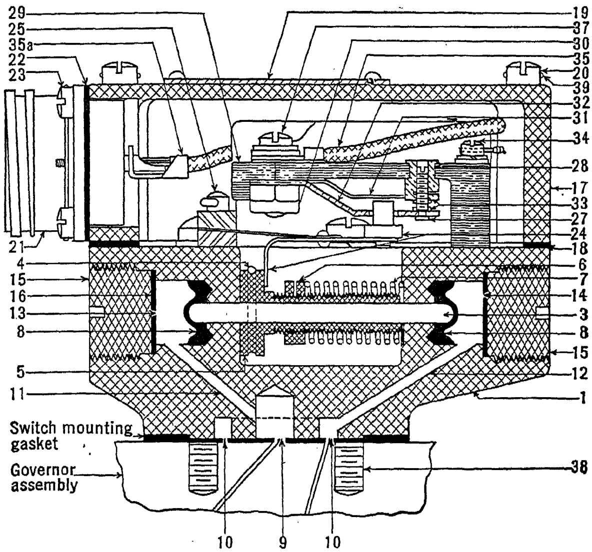
Where the low pitch blade angle settings in the propeller will not permit take-off rpm at rated manifold pressure while the plane is against the blocks, it is necessary to make the control system adjustment after a flight. This is accomplished by regulating the cockpit lever, in flight, until the tachometer reading corresponds with the engine's take-off rpm. When this reading is obtained, mark the position of the cockpit lever. Upon landing, return the lever to the marked position and adjust the stop at the control unit to restrict the control shaft from rotating beyond this point. The linkage system should then be readjusted with the cockpit lever approximately ⅛ in. from its full forward position and the control unit's pulley or lever against the adjustable stop.

If, on the test flight, take-off rpm cannot be obtained with the cockpit control full forward, it is because the constant speed unit is governing at an rpm lower than take-off. It will then be necessary to land and readjust the linkage system with the pulley or lever at the constant speed unit rotated sufficiently farther in a counterclockwise position to permit the obtaining of take-off rpm.

Hydromatic Propeller Pressure Cut-Out Switch and Auxiliary Feathering Pump. The feathering and unfeathering operation of Hydromatic propellers, installed on multiengine airplanes, should be checked at regular intervals. Since the auxiliary feathering pump and controls are used at infrequent intervals very little inspection will be re-

quired of these units between overhauls, except the customary feathering check.

The following troubles, encountered during feathering and unfeathering operations, and their remedies are applicable to feathering circuits employing the General Electric CD-2 pressure cut-out switch.



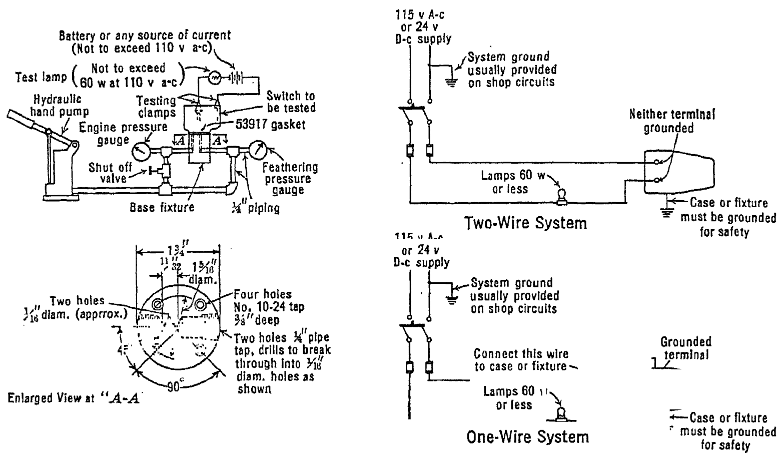
Courtesy General Electric Company

FIG. 228. Cross-sectional view of the G.E. Type CD-2 pressure cut-out switch.

GROUND CHECK WITH ENGINE DEAD

1. *If the feathering switch does not hold in when placing the propeller in the "full feather" position*
   a. Remove the pressure cut-out switch cover and gasket.
   b. Connect the two terminal screws together electrically and check that the feathering switch holds in.
      (1) If the feathering switch holds in properly, remove the pressure cut-out switch from the governor assembly. Remove the contact assembly (26) and examine the fingers (31) (32) and contacts (33). Check the flexible finger contact pressure and recalibrate the switch.
      (2) If the feathering switch does not hold in, the fault may be in the feather switch holding-coil circuit external to the pressure cut-out switch, or there may be insufficient voltage across this circuit. This trouble cannot be corrected by any operations on the pressure cut-out switch.

2. *If the propeller is not driven into the "full feather" position.*
   a. If possible, check that the auxiliary oil pressure builds up to at least 450 lb per sq in.
   b. Check that, by manually holding in the feathering switch, the propeller is driven into the full feather position. (Make sure that the feathering switch is held in long enough to drive the propeller into the full feather position if the auxiliary oil pressure system and the feathering mechanism are functioning properly. Holding in the feathering switch longer than necessary will only unfeather the propeller after it has reached the full feather position. This check is merely to note whether the propeller can be driven to full feather position if the auxiliary oil pressure is maintained a sufficient length of time.



Courtesy General Electric Company

FIG. 229. Test equipment for the G.E. Type CD-2 pressure cut-out switch.

   c. If the two preceding checks indicate proper operation of the auxiliary oil pressure and the feathering mechanism, the fault may be in the calibration of the pressure cut-out switch which may be opening the feathering switch-holding coil circuit before sufficient auxiliary oil pressure has built up to operate the feathering mechanism. Remove the pressure cut-out switch from the governor assembly and check its calibration. Recalibrate if necessary.
3. *The propeller is driven through the "full feather" position.*
   a. Remove the pressure cut-out switch cover and gasket.
   b. Disconnect an electrical connection from the pressure cut-out switch terminal.
   c. Touch the electrical connection to its proper terminal and push in the feathering switch. As the propeller feathers, pull the electrical connection away from its terminal.

(1) If the propeller continues to be driven through the full feather position, the fault will be found in the feathering switch or in the wiring external to the pressure cut-out switch. (A ground on the electrical connection between the feathering switch and the pressure cut-out switch, a ground within the feathering switch on a single-wire system, or a mechanical "sticking in" of the feathering switch will produce this effect.)

(2) If the propeller stops feathering when the electrical connection is pulled away from its terminal, remove the pressure cut-out switch and check its calibration. (This effect may be caused by plugging of the auxiliary oil pressure supply to the pressure cut-out switch, a faulty calibration of the switch, a mechanical interference within the switch, a ground on the adjustable finger (32) and contact (33) within the switch, or a "sealing" together of the switch contacts.

IF A DEAD ENGINE CHECK HAS INDICATED THAT THE SWITCH FUNCTIONS PROPERLY, YET FAULTY CONTROL IS NOTICED DURING THE GROUND FEATHERING, CHECK WITH ENGINE RUNNING OR IN FLIGHT DURING FEATHERING OPERATIONS

(A difference in operation between a dead and a running engine check tends to indicate that vibration may be affecting the feathering control circuit. This vibration may be causing a momentary opening in the control circuit which is sufficient to cause the feathering switch to open prematurely, thereby stopping the feathering of the propeller short of the full feather position. Before attempting to correct this trouble by operations on the pressure cut-out switch, it should be definitely established that the pressure cut-out switch is the source of this trouble. This may be easily done by connecting together the two wires on a two-wire system, or by grounding the one wire on a single-wire system, to the pressure cut-out switch and checking that the feathering switch will hold in with the engines running. This will obviously prevent the automatic positioning of the propeller in full feather but it will establish the fault within the pressure cut-out switch; in this event the following procedure is necessary.)

Remove the pressure cut-out switch from the governor assembly and check its calibration, noting particularly the lever spring and contact pressure adjustments. If the lever spring and contact pressure checks indicate proper adjustment, discretion may be used in bending the lever spring and the flexible finger (31) to increase the restraining force on the lever and the contact pressure to counteract the vibration periods which seemingly are the cause of the faulty operation. Recalibrate the switch.

A satisfactory test stand for calibrating and testing the cut-out switch is illustrated in Fig. 229.

CHAPTER XI

INSTALLATION

The detail method of mounting the engine on the aircraft is governed by the design ideas of the aircraft manufacturer. Mounts are generally of welded-tube construction, normalized chrome-molybdenum tubing being used. Low powered engines are usually rigidly mounted without any type of vibration absorbers. To reduce the vibration transmitted from the engine to the aircraft it is necessary to provide some type of vibration absorbers in mounting the high powered engines. Synthetic rubber absorbers are in most general use. They may be installed either at the junction of the engine to the mount, at the junction of the mount to the aircraft, or at both places.

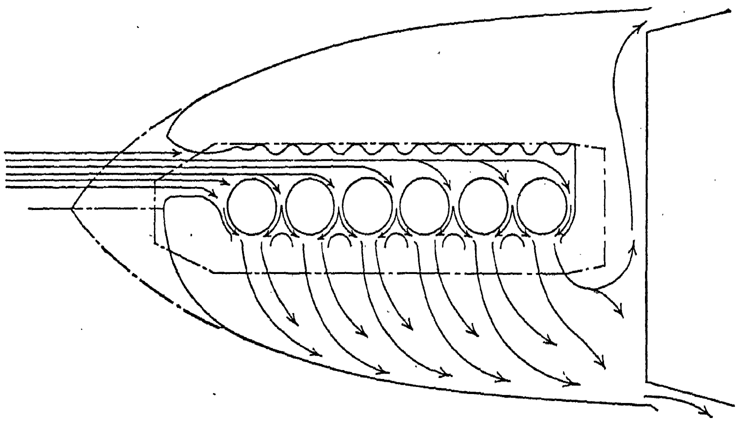
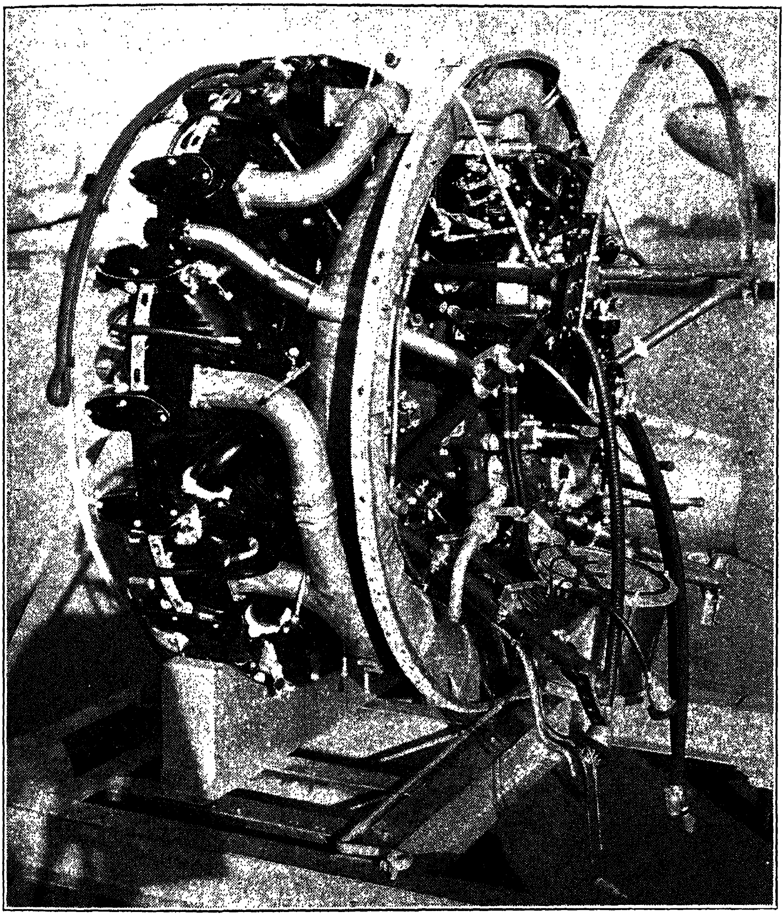


FIG. 230. Typical 6-cylinder in-line engine cowling arrangement showing cooling air flow.

To reduce fire hazard the engine is isolated from the main structure of the aircraft by a firewall. Firewalls are most commonly made of stainless steel (corrosion- and heat-resistant), although a properly constructed asbestos firewall may be used. To reduce the fire hazard further the power section and exhaust manifold may be isolated from the carburetor and accessory section by a stainless steel diaphragm.

To reduce the resistance of the engine to air flow, cowling is employed. Much research has been and is still being made to provide

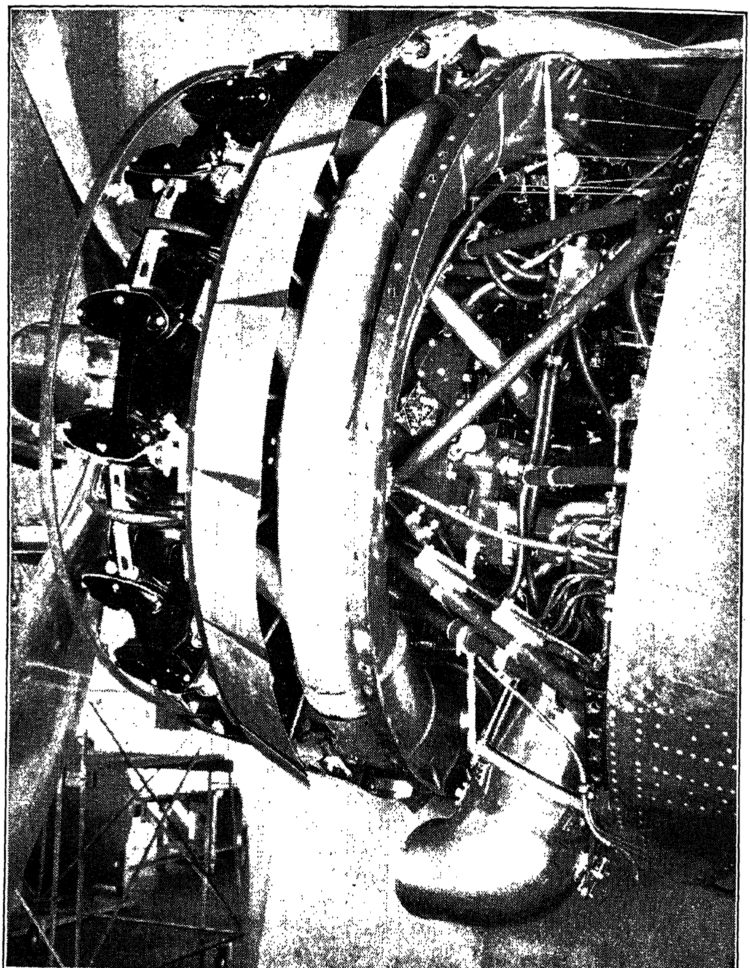
engine cowlings which offer the least resistance to air flow and at the same time allow sufficient cooling of the air-cooled engine. The liquid-cooled engine may, of course, be completely enclosed and the cooling radiator placed at any desirable location on the aircraft. To reduce the drag of air-cooled engine cowling, the cowling may be designed so that the engine receives sufficient cooling only with normal forward speed. In such cases it is necessary to use cowl flaps to provide sufficient air circulation and cooling at low forward speeds, such as during taxiing and climbing.



Courtesy Douglas Aircraft Company

FIG. 231. Demountable power plant unit ready for installation.

Power Plant Demountability. The phrase *power plant* is commonly used to include the engine, propeller, accessories, mount, brackets, lines, controls, and all other parts forward of the firewall. The trend of mod-



Courtesy Douglas Aircraft Company

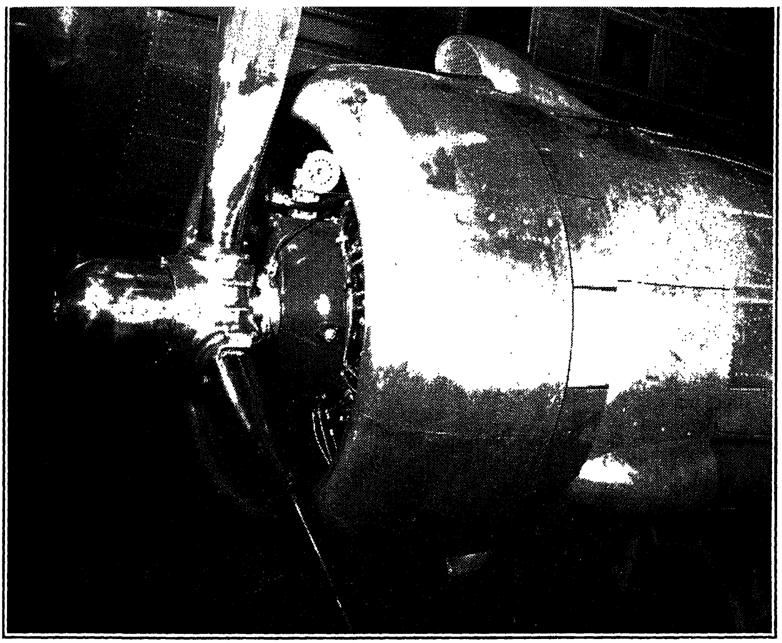
FIG. 232. Power plant unit, less cowling, installed on aircraft.

ern aircraft is to make the complete power plant demountable as a unit from the aircraft. A great reduction in time necessary for changing engines and increased accessibility for build-up of the power plant unit while it is mounted on a suitable workstand are the advantages

which accrue from a demountable unit. The demountable power plant, of course, requires that all controls, lines, and electrical leads be provided with a method of disconnection at or adjacent to the firewall.

Induction System. The purpose of the induction system is to supply adequate quantities of clean air to the engine under all operating conditions. Provisions should be made for heating the air as the engine may require.

Any air flow losses in the induction system will result in a corresponding loss of power output of the engine. To minimize the air



Courtesy Douglas Aircraft Company

FIG. 233. Complete power plant unit with cowling installed on aircraft.

flow losses the air passages should be of smooth interior, without sharp changes of curvature or section, and of sufficient area to supply air at velocities not greater than the velocity through the carburetor.

The intake opening should be located at a point where it will be subjected to a steady pressure regardless of the attitude of the airplane. By locating the intake opening as high as possible the likelihood of dirt entering the induction system is reduced.

If operating conditions are to be encountered where large quantities of dust and dirt are suspended in the atmosphere, it is extremely desirable that some means of cleaning the intake air be provided so that the engine life will not be abnormally shortened. Several types of air cleaners are in use.

To combat the problem of carburetor icing the most prevalent solution is the use of preheated air. The amount of preheating necessary depends upon the conditions under which the aircraft is to be operated and the type of carburetor installed. Two general types of carburetor air heaters are in use. One, the shroud-type heater, collects air which has passed over the outside of the exhaust system and mixes this hot air with the normal incoming cold air by means of an adjustable valve. The other, the intensifier type, provides a passage through the interior of the exhaust system for heating the air. The air preheater should be so designed that: the heat is equally distributed over the entire carburetor passage; the change of pressure at the carburetor is uniform with heater valve movement; the by-passed hot air is carried free from the cold air intake, and the intake system will withstand the pressures which may be built up by backfiring.

Exhaust System. The purpose of the exhaust system is to conduct the exhaust gas and heat away from the engine with a maximum reduction of exhaust noise and with a minimum effect upon the power output and the life or maintenance of the engine and its accessories. Some installations employ the short individual stack, but the majority of installations today are equipped with complete exhaust collector systems.

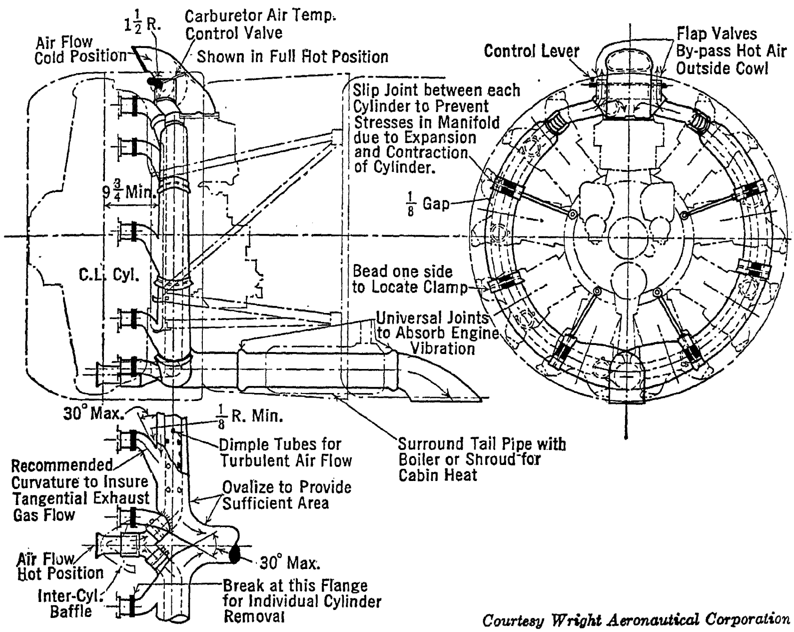
There are many factors that may contribute to excessive back-pressure of an exhaust system. The individual and combined effect of each of these factors must be carefully considered in the design of the system.

Because of the extreme and rapid variations in temperature, adequate provisions must be made in the design for the expansion and contraction of the individual parts as well as the whole system. Provisions must also be made for bracing the system to withstand vibration. The necessity for making provision for expansion of the system makes it difficult to eliminate leakage of the exhaust gases. Where leakage might damage adjacent parts of the installation, such as ignition wires, proper shields should be installed.

The high temperature and corrosive nature of the exhaust gas necessitate the use of a temperature- and corrosion-resistant material in exhaust system construction. Stainless steel and a corrosion- and heat-resistant steel, distributed under the trade name Inconel, are most

commonly used. At the expansion joints and other rubbing surfaces Inconel wears faster than stainless steel. Inconel has excellent corrosion- and heat-resistant properties, though, and is employed by some operators for the main collector ring construction with stainless steel clamps and wear strips at the expansion joints.

Stainless steel and Inconel are very similar in appearance. .When repairing exhaust systems by welding a different type of welding rod



Courtesy Wright Aeronautical Corporation

FIG. 234. Typical exhaust and induction system with intensifier-type carburetor air heater.

must be used for each type of metal. To distinguish between stainless steel and Inconel the following method may be used:

1. Make a test solution by dissolving 10 g of cupric chloric in 100 cc of concentrated hydrochloric acid.

2. Place one drop of the test solution on the sample of metal to be tested. Allow it to remain in contact with the metal for 2 min.

3. At the end of 2 min add slowly, one drop at a time, three or four drops of water to the test solution on the metal.

4. Wash and dry the metal sample.

5. If the sample is an 18-8 type stainless steel, a copper-colored spot will be left on the sample. If the sample is Inconel a white spot will be left at the point where the test solution came into contact with the metal.

Controls. Throttles, carburetor mixtures, propeller governors, radiator shutters, and other units require control from the cockpit. A choice of control systems is available. The cable and pulley control system is probably the most widely used. For engine controls $\frac{3}{32}$-in., 7 by 7, extra flexible cable is most commonly employed. The diameter of the pulleys is consistent with specification requirements as determined by the angle which the cable makes at the pulley. Turnbuckles are installed in the system for tightening the cable to the proper tension. When tightening a turnbuckle both ends should be held while the barrel is turned. This prevents twisting of the cable and runs both ends the same distance into the barrel. Several types of tools may be made up for preventing both ends from turning as the barrel is turned. After adjustment, the turnbuckle ends must have been screwed sufficiently into the barrel so that threads do not project outside the barrel. The turnbuckle is safetied by passing a wire through a hole in the center of the barrel and securing each end of the wire to an end of the turnbuckle.

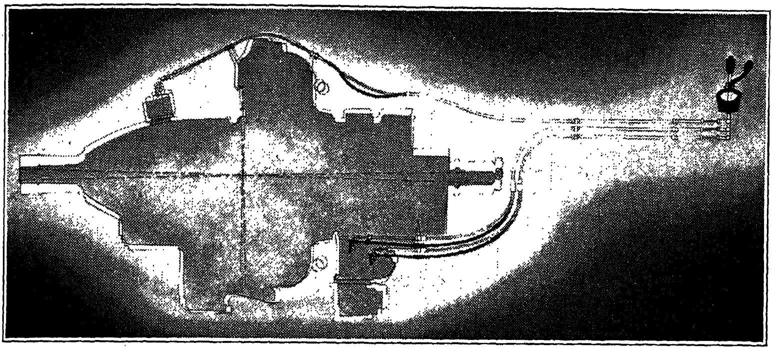
Cable fair leads are used to prevent fraying of the cable at points where it goes through partitions or at other points where it might come in contact with another object through vibration. It is at these fair leads and at cable pulleys that cables should be most thoroughly inspected for wear and fraying.

Rod controls are often used in conjunction with cable controls, cables being used from the cockpit to the firewall and rods forward of the firewall. When using rod controls it becomes necessary to use bell cranks at points where the direction of motion of the controls changes and at junctions of cable and rod controls. Bell cranks are generally provided with ball-bearing axles. The holes in the bell crank arms, to which the control rods attach, may or may not be provided with bushings. A bell crank which is not originally bushed should not be drilled and bushed unless the aircraft manufacturer or other reliable engineering staff establishes the fact that the arm will have sufficient metal left for the required strength after it is drilled for bushing.

Control rods are generally made of normalized chrome-molybdenum tubing, although some, especially torsionally loaded rods, are made of aluminum alloy tubing. It is some operators' experience that mild steel tubing (S.A.E. No. 1020 or 1025) has less tendency than chrome-molybdenum to fail as a result of the fatigue caused by vibration. The persistency of certain rods to fail is usually due to the fact that their natural vibration frequency is close to some disturbing frequency of the engine. If it is impracticable to change the natural frequency

of the rod by changing its length, its frequency may be changed by changing its weight. A heavier tube may be used or, as is sometimes done, a cable may be laid in the tube and welded with the tube to the rod ends.

Rod ends are either brazed, welded, or riveted to the rods. Electric flash welding is now being used extensively for securing rod ends to the rod. There are several types of rod ends. The most common is the male threaded end onto which may be screwed a clevis, ball bearing, or other type of end. Ball-bearing rod ends are usually packed with grease and sealed. The seal, however, will not prevent such light



Courtesy Simmonds Aerocessories, Inc.

FIG. 235. Installation diagram illustrating the necessity of flexibility in controls.

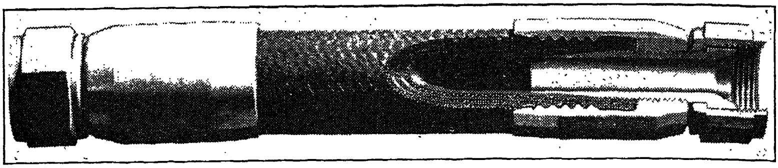
liquids as mineral spirits from entering and washing the grease from the bearing. This should be remembered when washing down the engine.

The flexible control, consisting of a wire or linked sections contained in a flexible spirally wound wire case, is frequently used for power plant controls. Such controls are packed with grease during manufacture and seldom require additional lubrication except at their ends. In the event that lubrication becomes necessary, a high grade of vaseline may be used. Lubrication can best be accomplished by removing the core, pumping the case full of lubricant, and then replacing the core.

Piping. The piping is a very important part of the power plant installation. The failure of a line or connection, especially of a fuel or oil line, is most certain to result in an engine failure.

Several types of tubing are in use for power plant piping. Fuel and oil lines and other lines of large diameter are generally made of a non-heat-treatable aluminum tubing distributed under the trade designa-

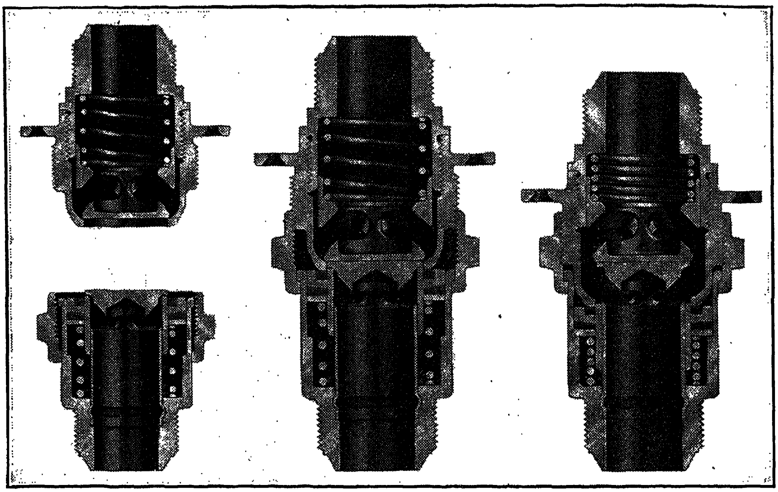
tion of 4SO or 52SO. This tubing does not have the tendency to harden and crystallize with vibration that the heat-treatable aluminum alloys do. If there should arise any doubt as to whether a piece of aluminum



Courtesy Aeroquip Corporation

FIG. 236. Flexible hose with removable end fittings.

tubing is the heat-treatable or nonheat-treatable type, this may be ascertained by applying a strong solution of caustic soda (lye) to a sample. If the sample is heat-treatable the copper in the aluminum



(a) (b) (c)

Courtesy Aeroquip Corporation

FIG. 237. Self-sealing coupling which prevents liquid from flowing from either line when coupling is disconnected (flange is for mounting on firewall or other partition): (a) disconnected, (b) partially connected, (c) completely connected.

alloy will cause it to turn black. Nonheat-treatable aluminum will react but will only turn white or a very light gray.

Smaller lines are often made of copper. With continued vibration the copper hardens and, if not annealed, failure will eventually result. Copper lines should be annealed at each engine change period. Cold forming also hardens copper and tubes should always be annealed

after cold bending. They may be annealed by heating to a deep red glow with a blowtorch or welding torch. After heating they may be immediately immersed in water. It is not necessary to anneal non-heat-treatable aluminum lines.

Fire extinguisher lines and extremely high pressure lines are commonly made of stainless steel. A copper alloy tubing distributed un-

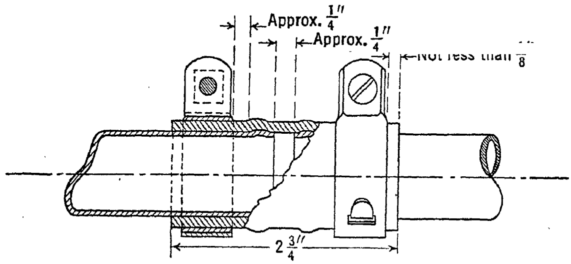


FIG. 238. Flexible hose connection.

der the trade name of Everdur, which has very good strength and fatigue characteristics, is also used for high pressures. Hydraulic lines are most commonly made of flexible rubber or synthetic rubber tubing. If the hydraulic fluid used is a mineral oil, both the inner tube and outer cover are of synthetic rubber. If the fluid is a vegetable oil, such as Lockheed fluid, a rubber inner tube is used with, usually, a synthetic rubber cover for protection against the deteriorating effects of fuel and oil. Vegetable oils cause synthetic rubber to swell.

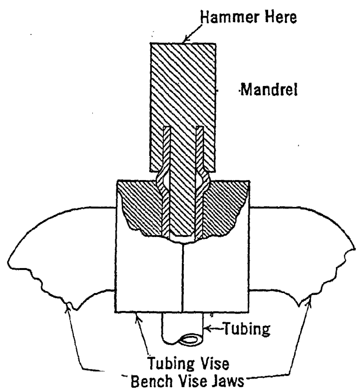


FIG. 239. Hand tool for beading soft, small-diameter tubing.

Installations with flexibly mounted engines must have flexible line couplings at the firewall. This is accomplished by the use of flexible hose connections. Fuel and oil line hose connections should utilize a synthetic rubber oil- and heat-resistant hose. Tubes should always be beaded at hose connections to aid in preventing the hose from slipping off the tube. Several types of tube clamps are in use. Those made of stainless steel are most favored for use forward of the firewall. One should make certain that the clamp is the right size for the hose used and that its inner surface exerts equal pressure about

the circumference of the hose. A hose clamp which is tightened all the way does not permit inspection for tightness. Such a clamp should be replaced.

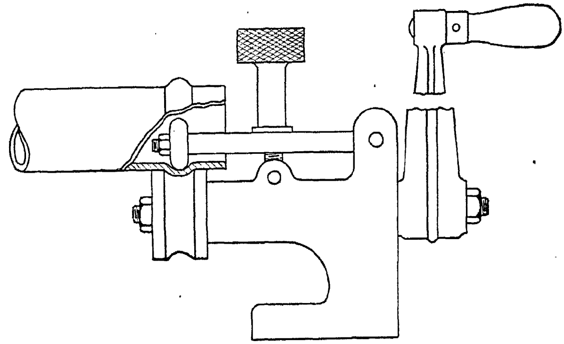
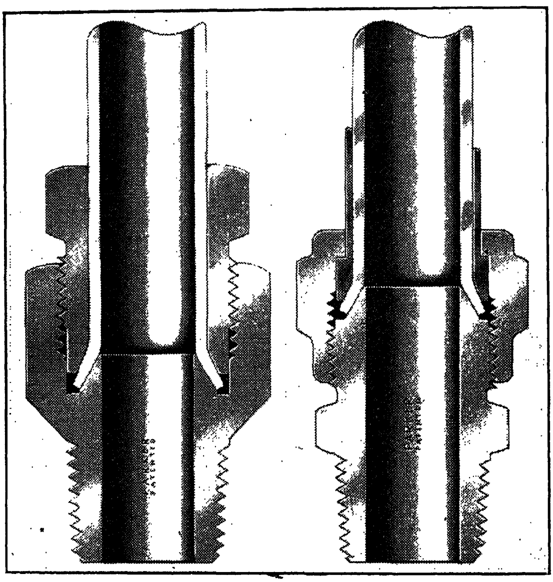


FIG. 240. Tool for beading relatively large-diameter tubing.



(a) (b)

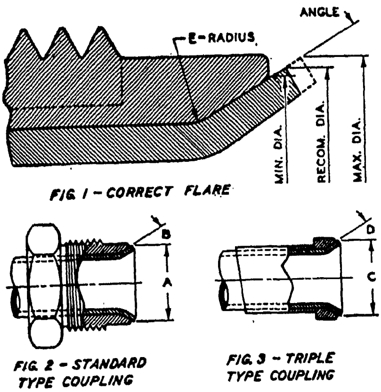
Courtesy Parker Appliance Company

FIG. 241. Cross-sectional view of rigid tube connections: (a) Parker "B" nut-type tube coupling (AC810); (b) Parker triple-type tube coupling (AC811).

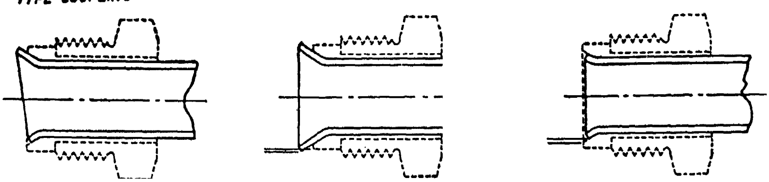
There are several types of rigid tube connections in use. However, standardization is progressing toward one type of rigid connection known commercially as the Triple Tube fitting or by the Air Corps

Specification AC811. Such a fitting offers substantial rigidity to the tube at the fitting through the use of a sleeve. The sleeve also provides the rubbing surface for the nut while tightening, and thereby eliminates rubbing of the nut against the tubing. With such a fitting the tendency is also reduced for the tube to turn with the tightening of the nut.

The success of rigid fittings is dependent upon their proper installation. The first step is to cut the tube ends squarely. A tubing cutter or tubing cut-off vise should be used. The ends should then be filed smooth and square. To insure filing the tube ends square the tube should be held in a tubing vise with a small amount of the tube protruding past the face of the vise. It should then be filed until the file runs flat across the face of the vise.



SIZE NO.	TUBE O.D.	RECOMMENDED FLARE DIAMETERS	
		A (STANDARD TYPE)	C (TRIPLE TYPE)
2	1/8	.187	.250
3	3/16	.310	.318
4	1/4	.353	.366
5	5/16	.418	.429
6	3/8	.478	.489
7	7/16	.541	.552
8	1/2	.658	.671
9	9/16	.721	.738
10	5/8	.783	.796
11	11/16	.887	.904
12	3/4	.950	.966
14	7/8	1.075	1.091
16	1	1.200	1.216
18	1 1/8	1.387	1.404
20	1 1/4	1.511	1.529
24	1 1/2	1.761	1.779
28	1 3/4	2.120	2.141
32	2	2.370	2.391



(a) (b) (c)

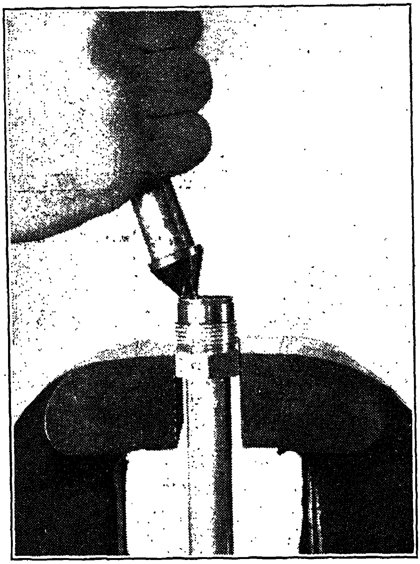
Courtesy Parker Appliance Company

FIG. 242. Upper figures 1, 2, and 3, correct tube flares. Lower illustrations, common errors in tube flaring: (a) tubing not cut square; (b) tube flared too long; (c) tube flared too short.

After the tube has been filed square, it should be burred inside and out, otherwise a leaky joint or split tube will result. Inside burrs may be removed with a machinist's scraper or a pocketknife. Outside burrs may be removed with a file. Care must be taken that the corners are not rounded off excessively.

The tube must be cleaned of all filings, chips, burrs, and grit. If there is no adhesive material, such as oil or preservative compound, inside the tube, it may be cleaned by blowing out with compressed air. Otherwise, a rag should be rammed completely through the tube.

Thin-wall soft copper and aluminum tube, sizes $\frac{3}{8}$ in. to $\frac{3}{4}$ in., may be flared with the ball-type flaring tool. The nut or triple nut and sleeve are slipped over the end of the tube and the tube is allowed to protrude about $\frac{1}{16}$ in. for $\frac{1}{2}$ in. O.D. tube. This distance is increased or decreased for different sizes of tubes. The nut and tube may be either gripped in a vise or held in the hand while flaring. The flaring tool is inserted and rotated in the tube while pressing outward and downward until the flare fits the nut. A slow circular wiping motion with firm, even pressure to hold the neck of the tool against the tube produces the best results. Continued flaring after the flare fits the nut will thin out the flare and should be avoided. After flaring, the nut of the tool is threaded onto the tube nut to even out the flare. When the triple-tube type of flaring tool is used the nut is screwed onto the male threaded portion of the tool. Excessive wrench pressure should not be used as it is not necessary to insure a smooth flare.

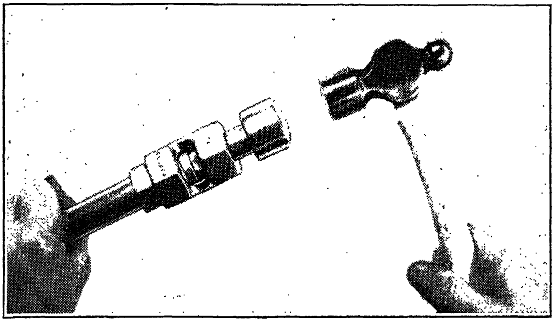


Courtesy Parker Appliance Company

FIG. 243. Ball-type tube-flaring tool.

For flaring tubes which cannot be flared with the ball-type tool there are several hammer-type tools in use. Their operation is simple. In any flaring operation, however, consideration must always be given to the even application of pressure about the complete flare and the correct diameter of the flare after completion. Several light blows produce a much better flare and are less likely to crack the flare than a smaller number of heavy blows. If the flare diameter is undersize the full clamping area of the fitting is not utilized. Too long a flare results in its jamming against the threads or seating against the bottom of the coupling instead of against the tapered seat and causing leaks which cannot be stopped even with strong wrench pressure.

The threads of aluminum alloy fittings have a tendency to seize and gall as they are screwed into place. To reduce this tendency the fittings are often anodized or the threads are copperized. To reduce further this tendency to seize and gall, a thread lubricant, such as Parker Threadlube, should always be used when assembling aluminum alloy fittings. Apply the lubricant to the male threads only, so as to reduce the possibility of any of the lubricant entering the line. In an emergency a satisfactory thread lubricant may be made by prepar-



Courtesy Parker Appliance Company

FIG. 244. Hammer-type flaring tool.

ing a mixture that is 25 per cent lead soap and 75 per cent mineral oil.

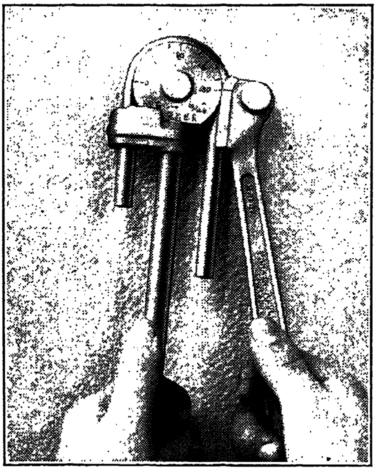
When tightening fittings whose threads have been lubricated, an excessive amount of load may be exerted on the threads without apparent knowledge of the wrencher. Care must be taken not to tighten the fitting nuts excessively. Incorrectly flared tubes cannot be made to seat properly by means of excessive torque, and excessive torque on correctly flared tubes tends to thin the flares and rupture or crack the tapered seat.

During disassembly of piping, fittings with pipe threads should be left in place wherever possible. Pipe threads are tapered and their continued disassembly and assembly will result in enlargement of the female threads to such an extent that a good connection cannot be made. This is especially true in cases where the female threads are of aluminum alloy.

Small-diameter copper and aluminum tubing may be bent successfully with several types of hand benders. A closely coiled spring just large enough to slip over the tube will prevent the tube walls from collapsing while being bent. For bending large-diameter tubes with

thin walls a bender utilizing a mandrel inside the tube to prevent collapsing of the walls is most generally used.

In an emergency tubes may be packed with some material such as sand, tar, or resin to prevent collapse of the walls during bending. To retain the filler in the tube it is necessary to plug the ends of the tube, unless a filler is used which is poured in hot and solidifies upon cooling. Tubes so bent must be thoroughly cleaned before being used.



Courtesy Parker Appliance Company

FIG. 245. Hand tube bender.

Cerrobend (distributed by the Cerro de Pasco Copper Corp., New York City) is a very low-melting-point alloy (melts at 160°F), which is very useful as a tube filler for bending. The procedure for bending tubes with this alloy is as follows:

1. Put Cerrobend in ladle with water and heat until the water boils.
2. Coat inside of tubing with light oil. This prevents the Cerrobend from adhering to the tube walls.
3. Plug one end of the tube with a cork or wooden stopper. Hold the tube in a vertical position with stopper at bottom end.
4. Pour water from ladle into tube. The water preheats the tube. After the water is all poured off, continue pouring. As the Cerrobend runs into the tube it will displace the water, forcing the water out at the top of the tube.
5. After the tube is full of Cerrobend, immerse it in cold water. If Cerrobend is allowed to cool slowly it becomes quite brittle. However, if it is rapidly chilled and solidifies quickly, it is very ductile.

6. When the tube is full of Cerrobend it may be bent as if it were a rod. The Cerrobend expands slightly as it solidifies (approximately 0.006 in. per in.). This holds the tube walls in tension while bending.

7. After the tube has been bent, the Cerrobend may be removed from it by immersing it in hot water.

Tube bends should be given as large radii as possible so as to minimize line flow losses caused by change of direction. Large radii also distribute the line bending loads over a greater area; this results in less likelihood of failure with the continued bending caused by vibration.

Bends must be sufficiently removed from the tube ends to provide sufficient straight distance for the fitting or hose connection. The minimum straight distance should be two times the O.D. of the tube for hose connections; one and one-half times the length of the sleeve for triple-tube connections, and two and one-half times the length of the nut for "B" nut (AC810) connections.

Lines should be secured to rigid structures at intervals frequent enough to prevent excessive vibration. Securing clamps must not make a metal-to-metal contact with the tube. Unless a special clamp with rubber liner is used, a couple of turns of friction tape or a piece of rubber hose should be placed around the tube at the clamp position.

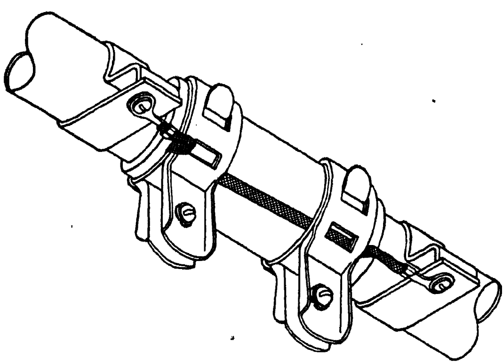


FIG. 246. Bonding of one tube to another across a flexible hose connection.

To prevent an electrostatic potential from building up between the various parts of the aircraft, because this causes interference with radio reception, it is necessary to bond all components and parts of the aircraft, one to the other, to provide a complete electrical circuit throughout all of them. Special tube-securing clamps incorporate a metal ribbon liner under a rubber liner which bonds piping to the securing

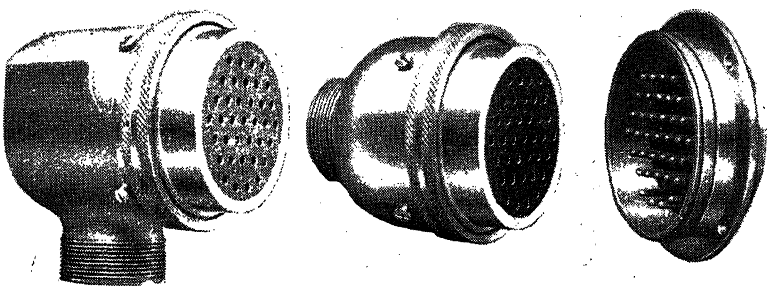
structure. If such special clamps are not used, piping may be bonded to some structure, such as the motor mount, with metal bonding clips and strips of flexible bonding braid. Before bonding to an anodized aluminum surface it is necessary to scrape off the anodic film at the point of contact because the film has a very high electrical resistance. At rubber hose connections the tubes may be bonded, one to the other, with a soft tinned copper or aluminum ribbon under the hose and contacting both tubes. Another type of tube bonding which affords a good electrical connection and which is easily inspected for breakage is shown in Fig. 246.

So that lines may be easily identified and traced they are given special identification markings. The color code for aircraft piping as specified by Army-Navy Certificate AN-9197-D is given below. Markings should be placed adjacent to the end of each tube section. Colored lacquer or colored tape which is given a clear lacquer coat for protection after installation may be used for markings.

Line	Color Band
Anti-icing	White — red
Compressed air — low pressure	Light blue — light green
— high pressure	Yellow — light green
Exhaust analyzer	Light blue — brown
Fire extinguisher	Brown
Flotation equipment	Light blue
Fuel	Red
Hydraulic	Light blue — yellow — light blue
Manifold pressure	White — light blue
Oil	Yellow
Oxygen	Light green
Pitot pressure	Black
Prestone	White — black — white
Purging	Light blue — yellow
Static pressure	Black — light green
Steam	Light blue — black
Vacuum	White — light green
Vent	Red — black
Water	White

Electrical Cables. Forward of the firewall electrical cables are shielded in a flexible conduit. Conduit fittings and electrical plugs and receptacles have until recently not been very well standardized. However, all new aircraft are now being equipped with standard AN (Army-Navy) conduit fittings, plugs, and receptacles. To eliminate the number of conduits leading to the firewall, multiple wire plugs and receptacles are used. The wires are conducted from the firewall through one, or as few conduits as possible, to a junction box whence

they lead off to the various points about the engine. When making electrical connections one should make certain that the contacting surfaces are clean and free from corrosion or else a poor circuit or no circuit at all will result. Fine sandpaper may be used for cleaning contacting surfaces. One should not use emery cloth or other abrasive which will aid in shorting one circuit to another if not completely cleaned from between the circuits. At engine inspection periods all connections should be inspected for tightness and safetying. Conduits should be inspected for chafing and security of mounting.



Courtesy Cannon Electric Development Company

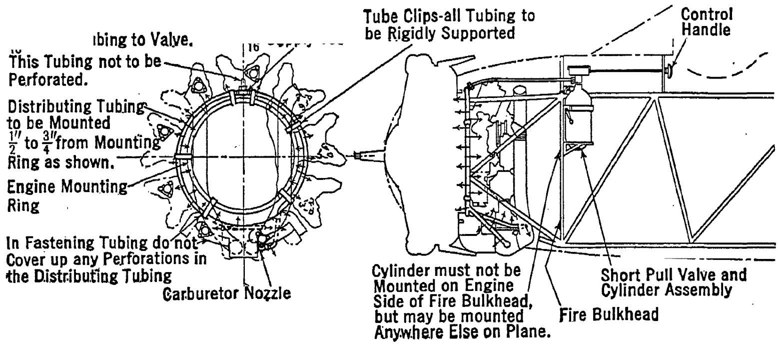
FIG. 247. Cable connectors used in airplane electric system for quick removal and installation of electric accessories. Arrangement of plug prongs eliminates the possibility of improper connection.

Fire Extinguishers. To combat the probable hazard of fire, the power plant section may be provided with a fire extinguishing system. The most universally used system employs carbon dioxide (CO_2) as the extinguishing (smothering) agent. The CO_2 is carried in a liquefied state in a special high strength cylinder which should be located aft of the firewall. On multiengine aircraft only one cylinder is usually carried, and it is centrally located in the aircraft. A selector valve is installed so that the discharge may be directed to any desired engine. A fire extinguisher line with frequent discharge holes is routed about the engine in such a manner as to discharge most advantageously the CO_2 for extinguishing any probable fire. The extinguisher usually terminates in a discharge fitting entering the carburetor air intake.

Several types of valves may be used for releasing the CO_2. The most popular type utilizes a disc in the head of the cylinder which is cut by a disc-cutting tube. Such an arrangement allows sudden release of the CO_2 and permits removal of the disc-cutting mechanism for inspection. It is not necessary to have a valve mechanism for each spare cylinder in storage.

Valve mechanisms are provided with a transparent window or other indicating device so that a visual inspection may be made to see whether or not the cylinder has been discharged. A safety discharge valve and line are provided to carry the CO_2 away from the cockpit or cabin, should the selector valve be in neutral or the lines clogged at time of discharge.

Siphon tubes in the CO_2 bottles are arranged so as to discharge the cylinder completely when in a particular position, either horizontal or vertical. Cylinders designed for vertical mounting have a black dot 2 in. in diameter painted on the bottom. Those for horizontal mounting have a black band painted around the cylinder.



Courtesy Walter Kidde and Company

FIG. 248. Single-engine carbon dioxide (CO_2) fire extinguisher installation.

Fire extinguisher systems should be tested at intervals of approximately 6 months. One method of testing is to discharge the system and then reinstall recharged cylinders. If it is not desired to discharge the system the disc-cutting mechanism and clearness of the line may be tested by replacing the CO_2 cylinder with a dummy cylinder to which an air pressure connection is made. The pull for releasing any type of valve should not exceed 50 lb and may be measured by attaching a spring scale to the release handle and pulling on the scale until the valve releases. Before being replaced, the CO_2 cylinder should be weighed to make sure it is fully charged. The fully charged weight is stamped on the neck of the bottle. If the weight is less than that specified by 4 oz or more, the cylinder should be recharged. The cutting tube edges should be inspected for sharpness and any cut disc should be removed before the cutting mechanism is replaced onto the cylinder.

Charged CO_2 cylinders should be handled with great care. They are potentially dangerous because of the high pressure within the cylinder. Should a free cylinder be inadvertently discharged it may gain a dangerous velocity if the discharge is in only one direction. However, a cylinder may be retained relatively easily while discharging before it is given a chance to gain velocity. While in storage, disc-type cylinders should have a discharge cap installed which has diametrically opposite discharge holes. The forces of the opposite discharges will counteract each other.

Engine Preservation. When an engine is to stand idle for any length of time precautions must be taken to prevent corrosion. Engines operated on leaded gasoline are subject to severe corrosion as a result of the by-products formed by the combustion of the fuel. In an engine which has been using leaded fuel, corrosion will start within a week unless the engine is run on straight unleaded fuel for at least one-half hour just prior to the idle period. Valve stems are particularly susceptible to corrosion which will cause sticking in the guides. Cylinder walls and the valve gear mechanism are also susceptible to corrosion within short periods of time if not properly preserved.

If an engine is to remain idle less than a week, it should be rotated daily by pulling the propeller through several revolutions. If the engine is to remain idle for more than a week, the following temporary preservation measures should be taken to prevent corrosion: It is most desirable that the engine be run on clear unleaded gasoline for at least one-half hour before the idle period. Excess oil is drained from the engine by removing the sump plug and strainers. This aids in preventing the accumulated oil in the engine from flowing into the lower cylinders and intake pipes. All spark plugs are removed and a small quantity of warm lubricating oil is sprayed through each spark plug hole. The engine is turned over for one or two revolutions to insure that all cylinder walls are covered. After the crankshaft is turned, it is good practice to give each cylinder another light spray. Rocker box covers are removed and the complete rocker and valve mechanism are sprayed with a mixture of 50 per cent lubricating oil and 50 per cent clear unleaded gasoline, and particular attention is given to the complete coverage of the valve stems. Dummy plugs are installed in the cylinder spark plug holes. Strainers are cleaned and replaced. The sump plug is replaced.

To put an engine back in operation after temporary preservation the dummy plugs should be removed from the cylinders and the engine rotated about 25 revolutions by hand. If the engine is a radial or inverted one, which has low spots in the intake pipes that might ac-

cumulate oil, the lower intake pipes should be removed and drained of any accumulated oil. The valve operation should be checked to make certain there are no sticking valves. The oil sump should be drained and the plug and safety replaced. The engine oil supply should be checked and replenished if necessary.

Engines which are to be placed in storage should be given a more thorough preservation than the temporary preservation described above. Engine manufacturers' overhaul manuals usually prescribe the preservatives to be used and the method of application for storage preservation.

CHAPTER XII

VIBRATION

One of the simplest forms of vibration is the vibrating weight suspended by a spring as illustrated in Fig. 249. It is said to be a vibrating system with one degree of freedom, that is, up and down. To commence the vibration of the weight it is necessary to displace it from its point of rest by some *disturbing force*. The range or width of its oscillation from its point of rest is known as the *amplitude*. The number of complete oscillations that the weight makes in a unit of time (usually per second or per minute) is known as its *frequency*.

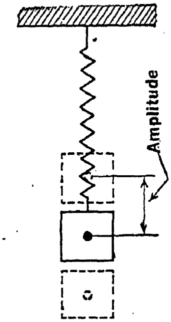


FIG. 249. A simple vibrating body suspended by a spring.

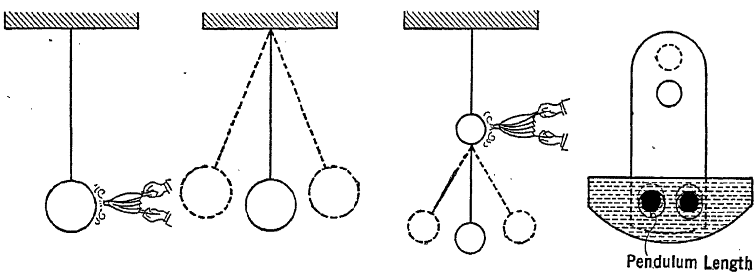
If, after the system commences vibrating it is no longer disturbed, it will continue to vibrate at its *natural frequency* and the amplitude will continually decrease until it has completely *damped* itself out. However, if the disturbing forces continues to act and is of the same frequency as the natural frequency of the vibrating system and is in phase with it, the system will continue to gain in amplitude. A good example of this is a person swinging in a rope-suspended swing. A very small amount of effort is necessary to swing the person through large amplitudes, if it is applied in proper timing. If it is not applied in proper timing, however, the amplitude of the swing is not very great. This condition of the disturbing force being of the same frequency as the natural frequency of the vibrating system and in phase with it is known as *resonance*. Resonance results in vibration of great amplitude.

Everything, no matter how rigid it may seem, has a certain amount of elasticity which allows it to deflect when subjected to a force. Hence, every object has some natural frequency. The natural frequency of the system of Fig. 249 could be changed either by changing the mass (weight divided by gravity) of the weight or by changing the strength of the spring.

There are many disturbing forces present while the aircraft engine is in operation, some of which are of relatively large magnitude. As

each cylinder fires, a "kick" is given to the crankshaft. This kick tends to twist the crankshaft. After the crankshaft has been twisted it twists itself back in the other direction because of its own elasticity and, of course, goes somewhat past its neutral point. The crankshaft has a certain natural torsional (twisting) frequency, and should these disturbing impulses from the cylinder firings occur at this frequency the crankshaft will build up a torsional vibration of destructive amplitude. In the higher powered engines it has been necessary to provide some means of dampening this torsional vibration caused by the firing impulses.

The method of dampening crankshaft torsional vibration is well illustrated in Figs. 250 and 251. The frequency of a simple pendulum is governed by its length and the mass of the pendulum. To dampen



Courtesy Wright Aeronautical Corporation

FIG. 250. If a simple pendulum were given a series of regular impulses at a speed corresponding to its natural frequency (using bellows to simulate a modified power impulse in an engine) it would commence swinging, or vibrating, back and forth as a result of the impulses.

FIG. 251. Another pendulum, suspended from the first (Fig. 250) and tuned to the same frequency, would absorb the impulses and swing itself, leaving the first stationary. The Dynamic Damper is a short pendulum hung on the crankshaft and tuned to the frequency of the power impulses to absorb vibration in the same manner.

the firing impulses, the Dynamic Damper must be in tune with (have the same frequency as) the firing impulses. It would at first seem that the pendulum length of the Damper and its mass are constant and therefore could only damp out the firing impulses when they were occurring at one particular frequency. However, as the frequency of the firing impulses increases, the rotary speed of the crankshaft increases. The increase in speed of the crankshaft increases the centrifugal force of the Dynamic pendulum; this has the same effect as increasing its mass and thereby increases its frequency, keeping it in tune with the firing impulses.

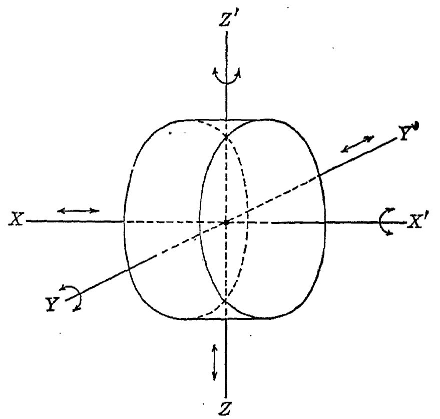
Because of the geometry of the articulated rod assembly of the radial engine the center of gravity of the pistons and rods shifts twice per crankshaft revolution to cause an unbalanced force which travels about the engine at twice crankshaft speed and in the direction of crankshaft rotation. This unbalanced force gives the engine a rotary shaking motion about an axis through the crankshaft center line. Some of the later engines are provided with a counterweight which rotates at twice crankshaft speed to counterbalance this disturbing force.

Owing to the slight unbalance of rotating parts there is an unbalanced force which travels about the engine at crankshaft speed.

Should a cylinder be missing fire there will be an unbalanced force occurring at a frequency of one-half that of engine rpm.

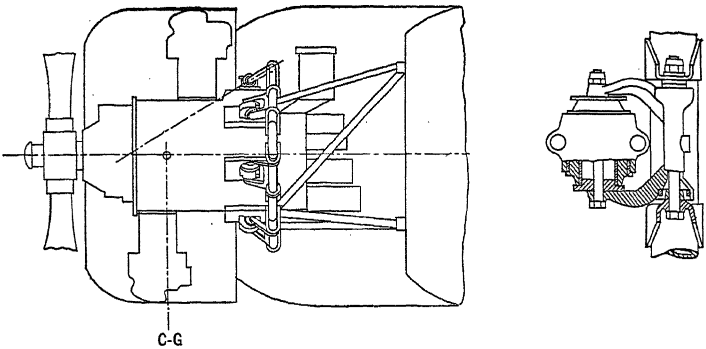
Static or dynamic unbalance of the propeller will cause an unbalanced force with a frequency of the propeller rpm. If the engine is geared, the propeller rpm, and therefore the frequency, will, of course, not be the same as the engine rpm.

There may also exist an unbalanced force caused by aerodynamic interference with the propeller blades, such as will occur when they pass close to any part of the airplane structure. The frequency of such an unbalanced force will be equal to the propeller rpm times the number of blades the propeller has.



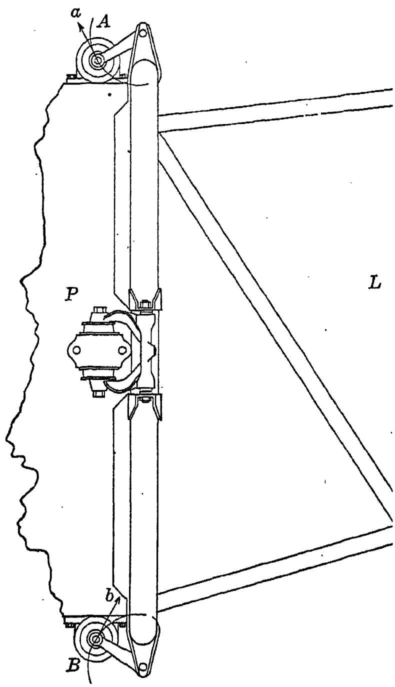
252. Axes along and about which any body may vibrate.

In the range from idling to full speed the engine may produce disturbing forces which are of the same frequency as the natural frequency of many of the airplane components. If these disturbing forces are transmitted to the airplane components, they will cause excessive vibration of the components and probably damage the components and annoy the passengers. It is, therefore, undesirable to transmit the engine vibrations to the airplane. However, since the engine cannot be completely prevented from vibrating, it must be allowed to vibrate, but its transmission of vibration to the airplane should be reduced as much as possible. This is usually done by means of rubber bushings inserted between either the engine and the mount, the mount and the airplane, or both.



Courtesy Wright Aeronautical Corporation

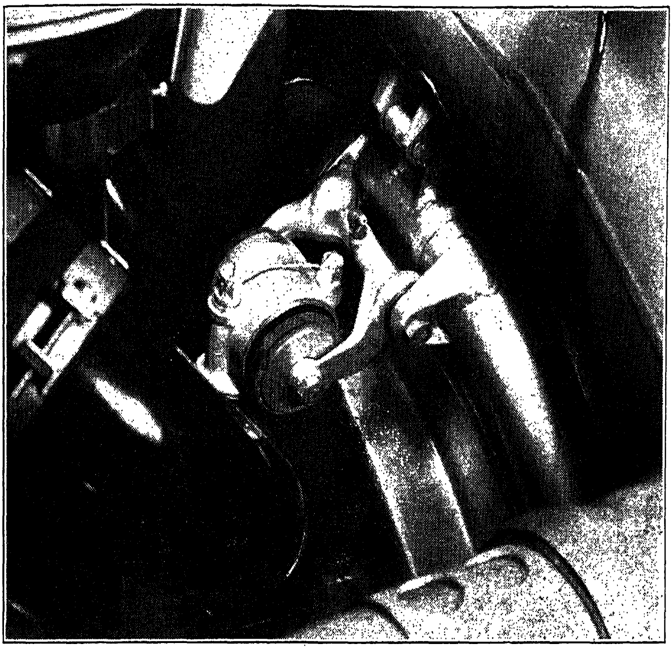
FIG. 253. Diagram of Dynafocal suspension, showing relative position of center of gravity and the intersection of axis of engine with axis of suspension links.



Courtesy Wright Aeronautical Corporation

FIG. 254. Diagram showing link movement in the Dynafocal method of suspension. Any movement at A is accompanied by a movement at B which retains the center of gravity of the engine in its same position.

In any type of vibration absorption mounting a basic requirement is that the engine be prevented from moving fore and aft firmly enough to permit satisfactory attachment of the piping, controls, and cowling. Until recently this requirement was met by arranging the shock-absorbing units so that the engine could not move fore and aft as a whole or in any part, but could only move in rotation about an axis

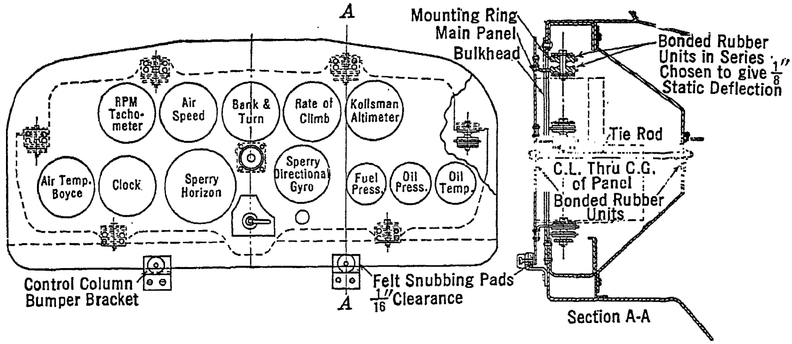


Courtesy Lord Manufacturing Company

FIG. 255. Installation of one of the link and bushing assemblies of the Dynafocal suspension mount.

through the crankshaft center line. Hence, the engine was restricted from pitching and yawing.

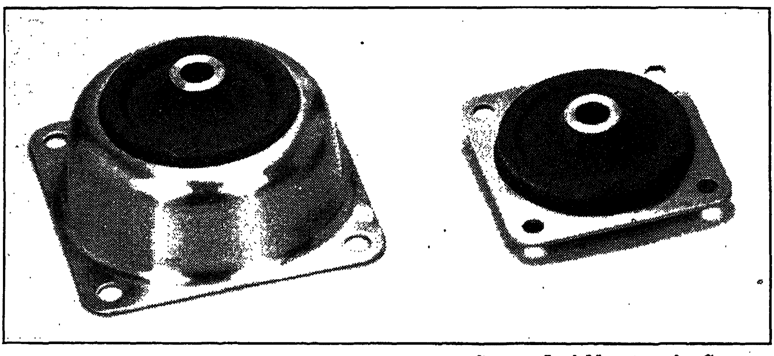
Every mass has three main axes passing through its center of gravity, about and along each of which it may vibrate. This means that there are six motions in which a body may vibrate, as is illustrated in Fig. 252. If it is restrained from moving in any one of these directions, any disturbing force tending to produce a vibration in that particular direction will aid in producing vibration in some other direction. Also, because of the rigidity in that particular direction a large amount of vibration from that particular disturbing force will be, in the case of the aircraft engine, transmitted to the airplane struc-



Courtesy Lord Manufacturing Company

FIG. 256. Instrument panel equipped with vibration-absorption mounting.

ture. Therefore, in order to keep to a minimum the amplitude of vibration of all of the six motions, and to reduce the transmission of any particular one or ones of the vibrations to the airplane structure, the engine should be so mounted that it is permitted movement in any direction in which it has a tendency to vibrate. This is the purpose of the method of Dynafocal suspension, illustrated in Figs. 253 and 254. The Dynafocal suspension supports the engine in such a manner



Courtesy Lord Manufacturing Company

FIG. 257. Shear-type bonded rubber vibration-absorption units.

that its center of gravity is held stationary, yet any rotary motion about the center of gravity and any lineal motion, except fore and aft, is permitted (within limits). A small amount of fore-and-aft movement of the center of gravity is permitted by the compression of the rubber bushings. Although the shock-absorbing units are located behind the center of gravity, the link suspension arrangement affords a center of gravity support which prevents drooping of the engine.

CHAPTER XIII

OPERATION

It has often been said that half of the maintenance is done in the air. Although this may not be altogether true, it is true that the service life and reliability of the engine are very dependent upon the type of treatment it receives both in the air and on the ground. Every mechanic who runs an engine on the ground should appreciate this fact and take every precaution to prevent its abuse.

Priming. For a fuel-air mixture to be ignitable in a cylinder the fuel-air ratio must be between the limits of approximately 0.062 to 0.125 lb of fuel per pound of air. We may consider the mixture ratio as the ratio of evaporated fuel to the air in the cylinder. Under conditions of starting, when the engine and induction system are cold, a much higher actual fuel-air ratio is required to produce a *fuel vapor-air* mixture in the cylinder which is within the firing limits. During cold weather starting a fuel-air ratio of fifteen times normal running requirements may be necessary to provide an ignitable vapor-air ratio. To provide the extra fuel required for starting a priming system generally is used.

Most engines equipped with downdraft carburetors use a single primer inlet into the induction system. Engines with updraft carburetors are usually provided with primer outlets leading into the intake valve passage on several of the top cylinders. Priming of the air intake passage or at the carburetor itself on engines with updraft carburetors would only result in fuel drainage at the air intake, with a subsequent fire hazard.

The amount of priming necessary for successful starting will depend upon the temperature of the engine and incoming air, the volatility of the fuel and the degree of mechanical atomization the fuel receives as it is injected into the induction system. The requirements will range from no priming when the engine is warm to maximum priming during extremely cold weather. Under conditions of extreme cold it may be necessary to heat the engine by means of a heating hood or other method before starting can be accomplished.

The procedure to be followed in priming and starting depends to a great extent upon the starter, carburetor, and primer equipment in-

stalled on the engine. Engines equipped with float-type carburetors, especially low powered engines which are started by pulling the propeller through by hand, are often primed by rotating the propeller with the ignition switch "Off." With the throttle closed in order to create maximum suction on the idle nozzle, rotation of the propeller will draw fuel from the idle discharge nozzle. While the propeller is stopped during the time the operator is obtaining another grip, the idle well fills with fuel so that on the next turn additional fuel is drawn in. Continuous turning of the propeller does not give this action as the idle well is soon emptied and air is drawn into the idle tube through the idle air bleed. Priming by this method is sufficient for warm weather starting, but as a rule does not provide sufficient fuel for cold weather conditions, and the primer system on the engine should be used. If no primer is provided the engine may be primed by squirting the fuel into the exhaust ports near the exhaust valve, and then turning the propeller over in the backward direction.

If the primer supply line is connected to the pressure side of the airplane fuel system the fuel pressure should first be brought to 2 to 3 lb per sq in. by means of the wobble pump before the primer is used. This will assure a supply of fuel at the primer pump. The charge is drawn into the pump slowly until it is completely filled; then it is discharged quickly. A quick discharge will create the maximum amount of mechanical atomization at the discharge nozzle with resultant maximum vaporization. Also, it will furnish the operator with an indication of the amount of charge within the pump. The number of pump strokes necessary for proper priming of any particular engine installation can only be determined by experience under varying conditions of temperature. As a rule the common cause of hard starting of the higher powered engines is underpriming rather than overpriming. However, excessive priming should be avoided as it will load the cylinders with raw gasoline and make the engine as difficult to start as if it were underprimed. Excessive priming also has a tendency to wash the oil off the cylinder walls and may result in barrel scoring or piston seizure. After a maximum of three unsuccessful attempts to start with priming, spark plugs should be removed and a small amount of warm oil should be sprayed into each cylinder to insure proper lubrication and compression and prevent damage to the cylinder walls. Should an engine be allowed to stand for a day or more after unsuccessful attempts to start, rusting of the piston rings and cylinder walls will occur unless these surfaces are protected by a fresh application of oil.

Underpriming is usually indicated by backfiring during starting.

When underpriming is suspected, additional priming should be administered cautiously.

In cold engines during cold weather a discharge of fuel from the supercharger drain is not necessarily an indication of overpriming. Since only the lighter fractions of the fuel vaporize at low temperatures the heavier fractions will remain as a liquid. A certain amount of the fuel which never vaporizes collects in and drains from the supercharger. At low temperatures the engine may not have sufficient priming even though fuel is flowing from the supercharger drain. The presence of raw fuel in the exhaust collector ring is an indication of sufficient priming, though, and may be an indication of overpriming.

Overpriming may prevent any firing from taking place or may result in only a few explosions with torching and white smoke emanating from the exhaust.

If there is evidence that the engine is overprimed, it will be necessary to clear the cylinders and induction system of the excess fuel. This may be done by turning the engine over several revolutions in the normal direction (not backwards) with the throttle wide open to prevent more fuel from being sucked into the system. Carburetors equipped with idle cut-offs should have the mixture control placed in the idle cut-off position while clearing excess fuel from the system. Turning the engine backwards will clear the fuel from the cylinders but will deposit it in the induction system whence it will again be drawn into the cylinders, especially the lower cylinders on radial engines, as soon as the engine is turned forward again.

All instructions applicable to priming with primer pumps are applicable to installations utilizing the carburetor accelerating pump for priming. Before priming with an accelerating pump one should make certain that the mixture control is set in the proper position to "open" the accelerating pump to the priming system valve. Otherwise, flooding of the induction system will result from operation of the accelerating pump. With the shorter priming system resulting from use of the accelerating pump and the greater capacity of the pump, relatively fewer strokes are required for priming with this system than with the separate primer pump.

Some engine installations are equipped with a primer fuel valve which merely connects the priming system with fuel under pressure in the main fuel supply lines. Such a valve may be either manually or electrically operated. The amount of priming fuel delivered will be dependent upon the pressure in the main fuel system and the length of time the valve is held open.

The engine should be started immediately after priming. A delay

in starting will permit the vaporized fuel to condense and result in too lean a vapor-air ratio for ignitability. Before attempting to start, one should place such priming device as may have been used in the " Off " or " Closed " position.

Prestarting Instructions. If the temperature is below 20°F it is good practice to heat the oil before attempting to start the engine, unless an oil dilution system is utilized. Heating may be accomplished by the use of an immersion heater placed in the oil supply tank or by draining the oil, heating it, and then refilling the tank. In the event that the latter method is used and it is probable that such conditions of temperature will be encountered in starting, it is well to drain the oil from the engine soon after it has been stopped and while the oil is still warm and thin.

During extremely cold weather it may be necessary to preheat the engine before starting. This may be accomplished by a heating hood or by placing the airplane in a heated hangar.

One should make certain that no loose tools or equipment are lying on or about the engine or airplane. If cowling is installed one should make certain that it is properly secured. Chocks should be in front of airplane wheels or parking brakes locked in " On " position. The quantity of fuel and oil in all tanks should be checked.

When an engine is standing idle, oil, or gasoline from the priming system, may drain into the combustion chambers of the cylinders. If this is not removed prior to starting, bent or broken link rods may result. If an engine has been standing idle for more than 1 hr the propeller should be pulled through at least two revolutions to make certain that no obstructions are present in the combustion chambers. If an excessive force is required to turn the propeller it will be necessary to remove the spark plugs from the lower cylinders of radial engines and from all cylinders of inverted engines so that the oil or gasoline may be drained from the combustion chambers. After standing for 8 hr or more some engines require draining of the oil sump before starting. The engine manufacturer's handbook will state whether or not this is necessary. Engines standing idle for long periods of time may accumulate oil in the inlet manifold tubes if these tubes have low spots from which oil may not drain. Such tubes should be removed and drained before starting is attempted.

When starting an engine a fire extinguisher should always be readily available for immediate use, especially during cold weather, because of the large amount of raw gasoline present while priming.

Starting. The exact procedure for starting will be governed by the particular engine installation. All items of the following instructions

are, of course, only applicable where the equipment mentioned is installed.

1. Set fuel tank selector valve on the correct tank for take-off.
2. Place propeller control in "low pitch" (high rpm) position.
3. Place carburetor heat control in "cold" position. This will prevent possible damage to induction system in the event of backfire.
4. Place cowl flaps in "open" position.
5. Close oil cooler shutters.
6. Place supercharger in low blower gear.

A. Float-Type Carburetor — Hand Starting

7. Raise fuel pressure to 3 lb per sq in. with wobble pump.
8. Prime as necessary. Close primer valve after priming.
9. With throttle closed turn propeller through several revolutions with ignition switch "Off."
10. Crack throttle very slightly.
11. Set mixture control in rich position.
12. Retard spark if magneto is equipped with adjustable spark. Advance as soon as engine begins firing.
13. Either verbally or by signal challenge and receive answer "all clear."
14. Turn ignition switch to "both on" and loudly announce "contact."
15. As the propeller is pulled through simultaneously operate the booster magneto or close the booster coil switch.

B. Float-Type Carburetor — Auxiliary Starting Unit

7. Raise fuel pressure to 3 lb per sq in. with wobble pump.
8. Prime as necessary. Close primer valve after priming.
9. Direct-cranking and inertia starters: Set throttle to give from 100 to 200 more rpm than the slowest idling speed.

   Cartridge starters: Set throttle to give from 200 to 400 more rpm than the slowest idling speed, because of higher initial speed obtained with this type of starter.
10. Set mixture control in rich position.
11. Adjustable spark need not be retarded unless engine tends to kick back with spark advanced. If spark is retarded, advance as soon as engine begins firing.
12. Inertia starters only: Bring up to speed of 12,000 rpm.
13. Either verbally or by signal challenge and receive answer "all clear."
14. Turn ignition switch to "both on."
15. Engage starter or fire cartridge starter by closing switch. Simultaneously operate the booster.

C. Holley Carburetor

7. Raise fuel pressure to 6 to 10 lb per sq in. with wobble pump.
8. Prime as necessary. Close primer valve after priming.
9. Set the throttle to give 700 to 800 rpm.

10. Set the mixture control in the full rich position. When an engine is to be restarted a short time after stopping, it is frequent practice to leave the mixture control in the fuel cut-off position, thereby locking a charge of fuel in the accelerating pump chamber. When using direct-cranking starters the fuel charge may be released after the starter begins turning the engine over, by moving the mixture control to the full rich position. When using inertia and cartridge starters it will be necessary to release the charge before engaging the starter, because of the short interval of starting.
12. Inertia starters only: Bring up to speed of 12,000 rpm.
13. Either verbally or by signal challenge and receive answer "all clear."
14. Turn ignition switch to "both on."
15. Engage starter or fire cartridge starter by closing switch. Simultaneously operate the booster.

D. Injection Carburetor

7. Set mixture control in "idle cut-off" position. In any other position fuel will flow from carburetor when fuel pressure exceeds pressure for which discharge nozzle is set (4 to 5 lb per sq in.).
8. Raise and maintain fuel pressure to about 10 lb per sq in. with wobble pump. In warm weather (80°F and above) 6 lb is more desirable.
9. Prime as necessary. Close primer valve after priming.
10. Open throttle very slightly.
11. Either verbally or by signal challenge and receive answer "all clear."
12. Turn ignition switch to "both on."
13. Engage starter and simultaneously operate booster.
14. If engine starts immediately, move mixture control to "automatic rich" position.

If engine does not start in 2 or 3 turns prime by moving mixture control out of "idle cut-off" position for approximately one-half turn of engine and then back to "idle cut-off." Maintain fuel pressure with wobble pump. If engine does not start within the next several revolutions, again prime by moving mixture control out of "idle cut-off" position. After engine commences firing move mixture control to "automatic rich" position.

General Starting Instructions. During the starting of all engine installations using pressure fuel systems, it is necessary that adequate fuel pressure be maintained by use of the wobble pump until the main fuel pump is revolving fast enough to maintain the correct pressure. This is particularly true immediately after starting.

Immediately after starting, the throttle should be moved slowly to the position at which the slowest steady running can be maintained. A quick opening of the throttle will admit an excessive amount of air

which will starve a cold engine of the proper fuel-air mixture and may result in backfiring. On engines equipped with carburetors having accelerating pumps, working the throttle back and forth rapidly for priming should be avoided either during or after starting. (An exception to this is priming by means of the accelerating pump on installations properly equipped for accelerating pump priming. In such cases priming is done before starting, with the valve connecting accelerating pump to priming system " open.") Operation of the accelerating pump before starting will introduce excessive amounts of raw fuel into the induction system of installations using downdraft carburetors. This raw fuel will either run out of the supercharger drain, resulting in a fire hazard, or be carried to the cylinders where it will prevent proper lubrication and cause scoring by washing the lubricant from the cylinder walls. On updraft carburetor installations the fuel will drain through the air intake with resultant fire hazard. Operation of the accelerating pump for priming immediately after starting, while the engine is cold, is a frequent cause of backfire with the accompanying fire hazard. If the engine is warm, pumping will tend to " load up " and possibly choke the engine.

The oil pressure should start registering on the gauge immediately after an engine is started. If there is no indication of oil pressure after 30 sec, the operator should stop the engine and determine the cause.

Inertia starters which are operated manually should be gradully accelerated by means of the hand crank to approximately 75 to 80 rpm of the hand crank. This speed corresponds to approximately 12,000 rpm of the flywheel. Excessive force on the hand crank at the beginning of the acceleration should be avoided. No more force than that exerted by one man should be applied to the hand crank.

The control switch of electrically operated inertia starters should be held closed for approximately 10 sec, or until such a time as the starter hum becomes constant.

In the event that the engine does not start and the inertia starter runs down while still engaged, disengagement of the starter jaws will not result when the engaging control is released. There should be no attempt to use the starter again with jaws engaged. The starter should be disengaged by turning the propeller forward about one-half revolution with ignition " Off."

For cartridge starters the proper size of cartridge to be used depends upon the type of starter, size and rating of the engine, and climatic conditions under which the units are operated. However, best results will be obtained from standpoints of economy, starter operation, and endurance, if the smallest size cartridge giving adequate

engine rotation is selected. Cartridges of a heavier powder loading than the allowable maximum shown below should not be used.

POWDER LOADING FOR CARTRIDGE STARTERS

Engine Displacement (Cu. In.)	Cartridge (Normal Conditions)	Maximum Allowable Cartridge	Engine Displacement (Cu. In.)	Cartridge (Normal) Conditions)	Maximum Allowable Cartridge
Under 985	14 g	14 g	1535	17 g	17 g
985	14 g	17 g	1820	22½ g	30 g
1340	17 g	17 g	Over 1820	30 g	30 g

If the engine starts, the exploded shell should be removed immediately after firing to prevent its sticking in the breech as the result of cooling of the wax coating on the cartridge casing. In opening the breech, the lever should be raised halfway to allow any pressure in the breech or tubing to escape through the relief valve before fully unlocking the breech. The starter should not be reloaded until ready for the next start.

If the engine fails to start, no more than three cartridges should be fired without allowing a period of at least 5 min for parts to cool. If a starting attempt fails to result in normal rotation of the engine another cartridge should not be fired until the trouble has been determined and corrected. If lack of performance is due to repeated failure of safety discs or of failure to obtain normal engine cranking with the safety disc remaining intact, the starter should be removed and disassembled for inspection.

In the event that cartridges fail to fire immediately upon the closing of the starting switch, the switch should be held closed for a perceptible interval of time to insure that delay in firing is not due to a relatively slow-acting cartridge primer element. If satisfactory results are not obtained, the electrical circuit of the breech should be checked. The cartridge should not be removed from the breech for at least 5 min after an unsuccessful attempt to fire. In an emergency, should the main electrical supply fail, the cartridge may be fired by using the current from three or more ordinary flashlight batteries connected in series.

Cartridge starter safety discs which have been ruptured may be removed by means of a sharp tool, but care must be taken not to nick the shearing edge of the disc holder. When making replacements, one must be sure to seat the disc firmly in the holder with the asbestos side facing the starter interior. Identification numbers are stamped on the copper side of the disc. Replacements should always be made with the

correct type of disc. If two discs rupture in succession, and the propeller can be turned easily by hand, the edge of the safety disc shearing ring should be inspected for a nick.

The engagement and release of the jaws of the direct-cranking electric starter are automatic and require no attention. Should starting with a direct-cranking electric starter not be accomplished within a maximum of 15 sec, the starter should be shut off for a minimum of 1 min to allow the battery to build up again.

Booster magnetos may be installed as an integral part of the starter, and operate without individual attention when the starter is operated. Booster coils may be operated by a switch whose control is integral with the starter control or they may be operated by a separate control. The procedure for operating the booster will depend upon the type of installation.

During extremely cold weather starting may be aided by turning the idle mixture control toward the full rich position. It should be readjusted after starting.

When the engine is turned over with the starter to clear out overpriming, starting can sometimes be accomplished during the clearing out if the ignition switch is left "On." If starting does occur, the operator should be prepared to close the throttle immediately to prevent overspeeding.

If starting is not immediately accomplished, repeated attempts should not be made until an investigation has been made to determine the reason. Several probable causes of failure to start follow:

1. Failure to perform properly the operations listed previously under starting instructions.
2. Lack of proper fuel pressure maintained at carburetor.
3. Leaky primer lines or primer pump packing.
4. Use of a low grade of fuel.
5. Water in fuel.
6. Air leakage in induction system.
7. Poor compression.
8. Magneto improperly timed.
9. Lack of good spark from booster coil or booster magneto. This may be checked by removing the high tension lead and holding it ¼ to ⅜ in. from some point on the engine or mount while operating the booster. For some installations it will be necessary to turn the engine over with the starter in order to operate the booster. The spark should jump from ¼ to ⅜ in. without difficulty.
10. Defective ignition harness. Even though the booster is producing sufficient voltage a defective ignition harness will not provide

sufficient voltage at the spark plugs. The harness should be tested as outlined on page 192.

11. Spark plugs may be fouled or may have incorrect gap setting.

Warm-Up. Immediately after the engine starts the operator should watch for an indication of oil pressure on the gauge. If oil pressure does not register within 30 sec after starting, the engine should be stopped immediately and the cause determined.

After the engine has started, the carburetor heat control is moved to the "hot" position. The engine is operated at the slowest idling speed at which smooth operation may be maintained for a period of at least 1 min. Prolonged idling below 800 rpm may result in fouled spark plugs. After approximately 1 min, the throttle is opened slowly to an engine speed of about 1000 rpm. The propeller is kept in "low pitch" (high rpm). The mixture control should remain in the "full rich" or "automatic rich" during warm-up.

The engine is run at 1000 to 1200 rpm until the oil inlet temperature reaches minimum operating temperature as specified by the engine manufacturer. The minimum operation temperature will be in the neighborhood of 40°C (104°F). The oil pressure gauge should be watched during the warm-up for fluctuations caused by air trapped in the oil lines. Any air so trapped should be allowed to escape by extending the warm-up period until the oil pressure stabilizes.

Cowl flaps, when installed, shall be open during warm-up. The operator should not attempt to warm the engine up more quickly by closing the cowl flaps in extremely cold weather. This may cause burning of the ignition system at the spark plug elbows.

Some engines are equipped with compensating oil pressure relief valves which are controlled by the temperature of the incoming oil. The relief valve is designed to produce initial high oil pressure for positive lubrication of the engine while the oil is still cold and thick. As the oil approaches the normal operating temperature the pressure will reduce to the normal operating pressure.

Ground Test. After the oil-in temperature has risen above the minimum normal operating temperature, the throttle is opened to give the recommended cruising manifold pressure with the propeller in the "low pitch" (high rpm) position. There should be no attempt to operate above 1200 rpm until the oil-in temperature has exceeded the operating minimum. If the oil pressure drops when the throttle is opened, the warm-up should be continued. Note should be made of the loss of revolutions when switching to one magneto at a time. The normal loss of revolutions when operating on one magneto varies widely among various engines, between right and left magnetos of any engine, and with

different engine speeds. The normal drop will have to be determined from experience. A drop of 50 per cent or more than the normal is an indication of excessive ignition system efficiency loss. This check should be made in as short a time as practicable. Continued running on one magneto at or above cruising horsepower may cause serious detonation.

The question may arise as to why there should be any change in rpm, even though the ignition system is inefficient, if a constant speed propeller is installed. With the constant speed governor set in the "low pitch" (high rpm) position, the engine rpm at cruising power while the airplane is chocked on the ground is lower than the rpm for which the constant speed control is set to govern. Therefore, the propeller will remain in full low pitch and the engine rpm will vary with the engine horsepower output. Curtiss electric propellers may be locked at any pitch setting.

The operation of the constant speed control should be checked by moving the cockpit control from the "low pitch" (high rpm) to the "high pitch" (low rpm) position and noting the drop in rpm. The control is then placed back in the "low pitch" (high rpm) position.

During the ground test the carburetor heat control should be in the "cold" position unless heat is required to prevent formation of ice. Oil shutter opening should be varied to control the oil temperature. Mixture control should be in the "full rich" or "automatic rich" position.

The oil pressure, oil temperature, fuel pressure, and ground rpm at the cruising manifold pressure should be checked. A check-off card should be used for recording the readings. The rpm at which the engine will turn at a given horsepower output with the airplane against the chocks will depend upon the propeller pitch angle and the air density. The normal *ground* rpm of the engine at cruising manifold pressure with the airplane against the chocks, and controllable or constant speed propeller in "low pitch" (high rpm) position, if used, should be established for the engine installation and a record of this normal ground rpm should be made in the engine log book. Engines which are to be checked on run-up at different altitudes should have the normal ground rpm established for two or more altitudes at least 1000 ft apart. When engines are checked on run-up these normal ground rpm's are a criterion of the engine performance.

Except on the initial running after overhaul, any appreciable change in the oil pressure from the normal, under normal rpm and temperature, may indicate troubles within the engine or oil system which should be investigated. The oil pressure will vary with rpm and tempera-

ture and need cause no alarm by falling off when the throttle is returned to idling with the oil hot.

General smoothness, engine speed, manifold pressure, carburetor air temperature, fuel-air ratio, cylinder temperatures, oil temperature, and oil pressure give the most satisfactory indication of the performance of the power plant. If any one of these appears irregular, the engine should be throttled and, if the cause is not apparent, the engine should be stopped.

On engines equipped with two speed superchargers, the clutch should be checked for proper operation. With the engine operating at approximately 1200 rpm the clutch control lever is moved to the "high" position. After a minimum of 5 min running time in the high ratio at approximately 1200 rpm the throttle is opened to obtain the recommended cruising manifold pressure. After the engine speed has stabilized, the manifold pressure is observed and the clutch control is shifted to the "low" position. A decrease in manifold pressure of approximately 2 in. Hg will indicate proper functioning of the two-speed supercharger drive. In changing from one supercharger blower gear ratio to another the control should be moved directly to the other ratio and not allowed to remain in the neutral position. Changing from one gear ratio to another should not be performed at intervals of less than 5 min, so as to allow the heat generated by the clutch plates to be dissipated.

Run-In after Installation. The original run-in of an engine after installation should be made with the cowling removed. This will permit complete inspection of the installation details and their operation. It will also provide better cooling for air-cooled engines. When an engine is running while the airplane is standing still, the flow of air for cooling is much less than when the airplane is flying, so that unless the power is limited the cylinders will overheat. Continuous running on the ground should not exceed approximately 1500 rpm. The cylinder temperatures should be checked continuously to make certain that they do not exceed the recommended maximum, which will be approximately 400°F (204°C) for air-cooled cylinder heads. Cylinder head temperatures are likely to increase rapidly after passing 400°F (204°C).

After the engine has been started and warmed up according to previous instructions, it is desirable that it be run at a speed not to exceed 1500 rpm for a period of at least 30 min to assure proper engine lubrication system operation.

After the run-in the engine should be ground-tested. The oil pressure and fuel pressure are adjusted as necessary. The idling adjust-

ment is made while the engine is warm. The acceleration is checked. The constant speed governor is adjusted as outlined on page 299. To check the low pitch stop setting of the propeller constant speed control unit, it is permissible to run the engine at its rated "take-off" manifold pressure with the propeller control in full "low pitch" for a period not to exceed 5 sec. Magnetos should never be checked under these conditions. The operation of all controls is checked. After the engine is stopped the safetying of all controls is checked. The complete engine installation is checked. The oil strainer is removed and cleaned of any foreign matter that might have accumulated during the run-in.

Improper Functioning of the Engine. There are three main sources of trouble which may cause improper and irregular operation of the engine. They are (1) ignition, (2) carburetion, and (3) compression. In attempting to determine the specific cause of improper functioning, an attempt should first be made to determine whether the trouble is general or local; that is, whether all cylinders are affected or just one or several. Feeling each cylinder or its exhaust pipe immediately after the engine has been run is a very good method of determining whether all cylinders have been operating. A cool cylinder will indicate that it has not been firing properly. After the trouble has been classified as local or general an effort should be made to determine which main source of trouble (ignition, carburetion, or compression) the engine indicates. After this, the specific troubles which may be causing the main trouble should be enumerated. The specific trouble is located by systematically eliminating by check the probable specific troubles, starting with those most likely to be present.

A properly operating but roughly running engine may be caused by one of the following conditions:

1. Propeller out of balance, out of track or blades not all set at same pitch. This is checked by installing a propeller from another engine which is known to run smoothly.
2. Propeller hub nut not sufficiently tight or cones not seating properly.
3. Engine mount bolts not tight.
4. Cracked or broken engine mount members.
5. Engine mount shock absorbers worn sufficiently to permit metal-to-metal contact at the shock mounting points.
6. Contact of the shock mounted installation with some portion of the rigid installation.

Hydromatic Propeller Operation after Installation. After installation of a Hydromatic propeller the blades should be moved into low pitch by means of blade torque arms and the blade angles should be

checked to make sure that they are all the same and that they agree with the low pitch stop setting. This check indicates that the correct relationship between the blade gears and cam gear has been obtained at installation. Unfeathering the propeller with oil pressure before this check is made may result in serious damage to the mechanism should the dome assembly have been installed with incorrect angular relationship between the rotating cam gear and the blade gear segments.

With the governor control set in the "low pitch" (high rpm) position start and warm up the engine in the normal manner. Upon starting the engine, the outboard end of the propeller cylinder will fill immediately with engine oil at normal engine pressure. This pressure will hold the blades against the low pitch stops.

After the warm-up or run-in of a newly installed engine has been completed the throttle is opened to some intermediate engine speed, for example, 1800 rpm. The governor control is moved to the "high pitch" (low rpm) position. The engine will be turning faster now than the speed for which the governor is set and the governor will supply oil to the inboard side of the propeller piston. When the inboard end of the cylinder has filled (this should require 35 to 45 sec) the propeller will move toward high pitch and the rpm will drop to the minimum governor speed. If the governor control is moved now several times between the minimum governor setting and the 1800 rpm position, all air will be eliminated from the system.

Air trapped in the propeller and shaft system causes hunting or surging of the governor. The action of centrifugal force on the oil in the propeller throws it to the periphery of the cylinder. This forces any air which may remain in the inboard end of the cylinder to the center of the system whence it is expelled through the governor during the underspeed cycles and replaced with governor oil during the overspeed cycle. Similarly, any air in the outboard end of the cylinder is expelled through the engine shaft and replaced with engine oil. It is for this reason that moving the governor control through the quadrant several times will eliminate air from the system and permit accurate governing and rapid response.

It is advisable to test the feathering and unfeathering operation of the propeller on the ground after completion of the installation. Because there are several ways in which high pressure oil may be obtained for operating the propeller's feathering feature (individual pumps using engine oil, central pumping system using low viscosity oil, airplane's hydraulic system, etc.) and because of the limitations prescribed by individual engine manufacturers on use of low viscosity

oils, it is not feasible to discuss here the procedure for testing the feathering operation in each type of installation.

The following procedure is recommended for testing the feathering operation where the individual electric-motor-driven pump, using engine oil, constitutes the auxiliary pressure system.

1. Complete engine warm-up.
2. With engine operating at approximately 1500 rpm and approximately 22 in. Hg manifold pressure, close the propeller control switch. When the propeller has reached the full-feathered position the control switch will open automatically. The rpm will have dropped to about 500.
3. When the propeller has reached the full-feathered position again close the control switch and hold it closed, while the propeller is unfeathering, until approximately 1000 rpm is reached.
4. Release the switch and the propeller will return to the control of the governor at 1500 rpm.
5. Before repeating the above sequence of operations, the engine should be operated at approximately 1000 rpm for at least 2 min.

The above method of testing the feathering operation with the engine running has several important advantages not attainable when feathering is carried out with the engine stationary. They are:

1. It is not necessary to drain the engine sump after a feathering cycle in order to avoid loading the engine with oil. The engine scavenger pump returns the excess oil to the tanks.
2. The oil is hot and the propeller feathers and unfeathers faster and on a lower pump pressure, thereby reducing the load on the electrical system.
3. The hot oil and rotating engine parts allow a lower engine back-pressure during feathering and unfeathering. (This back-pressure is caused by the displacement of approximately 3 qt of propeller oil into the engine lubricating system when the propeller is feathered or unfeathered.)
4. The feathering test is made with oil of relatively lower viscosity which approaches more closely the conditions under which the propeller would be feathered in flight.

Taxing. During all operations of the engine, either on the ground or in the air, it must be remembered that fast cooling of the engine may be just as injurious to it as fast warming. Always open and close the throttle gradually and do not accelerate the engine so fast as to cause detonation. Besides the abuses inherent to quick warming and cooling it should be kept in mind that quick changes of speed impose excessive loads upon the engine. This is particularly true of geared and supercharged engines turning propellers weighing upwards of 500 lb and

blowers at speeds ten times the speed of the crankshaft and more. A little forethought as to what will be required for the maneuver ahead will prevent excessive blasting of the engine.

Stopping. Unless the engine has been allowed to idle after hard taxing or ground test, the cylinders will be above the minimum normal operating temperatures. The engine should be idled for a sufficient length of time to allow the cylinder temperatures to drop below the minimum normal operating limit. This should require about 1 min.

Engines not equipped with carburetors having idle cut-off will have to be stopped by either cutting off the ignition or closing off the main fuel supply. Cutting off the main fuel supply may not be practical in installations where the control valve is a distance from the carburetor. In either instance the engine should be stopped in a manner which will tend to reduce the possibility of kick back.

1. Idle the engine with the mixture control in the lean position until the cylinders are below minimum normal operating temperature. With the mixture control in the lean position there will not be so great a tendency for the idling system to load up the induction system.

2. Slowly open the throttle to give a speed of 700 to 800 rpm. Immediately turn off ignition switch and then open throttle wide.

3. After the engine has stopped move the mixture control to the full rich position and leave the throttle open.

If the engine is to be stopped by shutting off the fuel supply, the fuel supply valve should be closed while the engine is idling. As the fuel supply at the carburetor becomes inadequate the engine will start missing. When this occurs the starving should be aided by opening the throttle wide.

The following procedure should be used for stopping an engine equipped with carburetor having idle cut-off.

1. Idle the engine until the cylinders are below the normal operating temperature.

2. Slowly open the throttle to give a speed of 700 to 800 rpm.

3. Move the mixture control to the "idle cut-off" position. Open the throttle to aid in starving the engine.

4. After the engine has stopped, turn off the ignition switch. Leave the mixture control in the "idle cut-off" position.

After an engine has been stopped the main fuel supply should be closed off. When an engine is to remain out of service for a day or more, the oil sump drain plug should be removed to prevent accumulation of oil in the engine and reduce the possibility of oil accumulating in the intake pipes and combustion chambers of the lower cylinders. This procedure is particularly desirable on installations which have

high oil tank locations and are not provided with check valves to prevent oil from flowing back through the oil pump into the engine. A receptacle should be placed under the oil sump opening to catch any drain oil.

The blade angle position of controllable or constant speed propellers when stopping the engine will be determined by the conditions to be encountered after stopping and upon the type of propeller used. Electrically controlled propellers may always be stopped in the " low pitch " position.

If the engine is to remain stopped for a considerable time, counterweight-type propellers should be placed in the "high pitch" (low rpm) position before stopping. This will protect the propeller piston from dust and sand that might accumulate while the engine is idle. Also, the oil will be forced from the piston; if left there, the oil may congeal in cold weather and prevent shifting to high pitch.

Hydromatic propellers may be stopped in the " low pitch " position. There are no exposed working parts to accumulate dust or sand and there will always be oil in the dome, no matter which position the piston is in.

Flight. The details of flight operation vary with different installations. The engine and airplane manufacturers' instructions must be consulted for these details. However, those points which in general pertain to all installations will be briefly discussed here.

With the fuel-air ratio and other conditions remaining constant, the horsepower output of an engine is almost directly proportional to its mass (weight) air consumption. The mass air consumption of the engine is mainly dependent upon the pressure at the cylinder inlet ports, the air density, and the number of suction strokes per unit of time. The air density at the cylinder inlet ports is dependent upon the air pressure and temperature. Disregarding air temperature, a rough estimate of the mass air consumption may be made if the cylinder inlet pressure and engine rpm are known. The manifold pressure gauge provides a means of determining the cylinder inlet pressure. The tachometer indicates the engine rpm. Hence, it follows that the engine horsepower may be roughly specified in terms of manifold pressure and rpm. It is the general practice of engine manufacturers to specify the limits of operating horsepower of supercharged engines by this means. To estimate more closely the horsepower output of an engine it is, of course, necessary to take into consideration the temperature of the incoming air and also the pressure at the cylinder exhaust ports.

The maximum rated horsepower of an engine is usually referred to

as the "take-off" horsepower. It is the highest permissible horsepower at which the engine may be operated, and then for only short periods of time. For take-off the permissible limit is usually 2 min, and may be extended to 5 min for emergency climb or military use.

Supercharged engines which are rated at altitude are capable, at low altitudes, of developing a maximum power in excess of the rated take-off horsepower. To prevent exceeding the rated power it is necessary to control the manifold pressure by a partial closing of the throttle when the engine is operated below the altitude at which it is rated. Throttle stops are usually provided on the control quadrant to limit the travel of the throttle control past the point where the rated manifold pressure would be exceeded when operating below the rated altitude. These stops should be so designed that they may be moved out of the way when the airplane approaches rated altitude.

The normal "rated" horsepower of an engine is the horsepower rating specified by the engine manufacturer. It is the maximum horsepower at which the engine may be operated continuously and is sometimes referred to as the *rated (except take-off) horsepower.*

Engine manufacturers establish maximum operating outputs for the various conditions of flight. These maximum limits are based upon outputs which conduce to maximum reliability and service and minimum operating and maintenance cost. These operating limits should be strictly adhered to. A typical chart of operating limits for an air-cooled radial engine with a one-speed single-stage supercharger is shown in Table II.

Just prior to take-off the engine should be given a ground test similar to that previously described in this chapter. Since the engine will be operated at high output during the take-off it is desirable that the intake air be cold to aid in preventing detonation. Unless it is necessary to prevent ice formation the carburetor heat control should be placed in the "cold" position. Mixture controls shall always be in the rich position. Oil cooler shutters should be full open except during extremely cold weather. Cowl flaps should be in the open position.

Take-offs shall not be started until the oil and cylinder temperatures are up to the minimums specified. Some manufacturers also specify maximum cylinder temperature limits for take-offs. If maximums are not specified the temperature must be low enough to insure that the maximum operating limits are not exceeded during the use of take-off power.

With the propeller set for take-off rpm, the throttle is opened slowly. On short runways it may be desirable to attain approximately cruising manifold pressure before releasing the airplane brakes. During the

TABLE II

Operations Limit Chart for a Twin-Row Radial Engine

(Single-stage, one-speed supercharger; 7:15 to 1 blower ratio; 1830 cu in. displacement; normal rated horsepower, 1050 at 2550 rpm; 39.5 in. Hg manifold pressure at 7500 ft altitude. *Courtesy of Pratt and Whitney Aircraft.*)

Operating Condition	Alt. Ft.	Engine RPM or Gov. Setting	Max. Man. Press. In.Hg.	Mixture Control	Oil-In Temp. °F	Oil Press. Lbs/In²	Fuel Press. Lbs/In²	Cyl. Heads Max. °F	Cyl. Barrels Max. °F	Cowl Flap	Approx. Fuel Cons. Gal/Hr
(Pull thru) Start	—	500–800 ½ min.	1/10 Throt.	Idle cut-off then Auto. Rich	—	(300)	10 15±1	—	—	Open	—
Warm-Up	—	1000	—	Auto. Rich	—	—	15±1	401	334	"	—
Ground Test	—	Low Pitch	30.0	"	104–185	85+15–5	"	450 248	334	"	—
Take-Off	—	2700	48.0	"	"	"	"	500	"	"	150
Military or Climb (5 min)	3700	2700	46 5	"	104–212	"	"	"	"	"	150
Normal	7500	2550	39.5	"	104–185	"	"	"	"	As req'd	126
75% Power	12000	2325	31.5	"	140–167	"	"	450	"	"	75
Cruising Max.	15000	2325	28.0	Auto. Lean	140–167	85+15–20	"	"	"	Closed	56
Cruising Rec.	12300	-2175	29 5	"	"	"	"	"	"	"	54
Cruising Rec.	5500	1350	30.0	"	"	"	"	"	"	"	31
Dive	—	3060	—	Auto. Rich	104–185	"	"	500	"	"	—
Glide and Descent	—	(Cruise RPM)	—	"	104–185	"	"	450	"	"	—
Approach for Landing	—	(Cruise RPM) (or 2550)	—	"	"	"	"	500	"	½	—
Stop	—	1000 (LowPitch)	—	Idle Cut-Off	—	(15)	"	401	"	Open	—

take-off the permissible take-off manifold pressure should not be exceeded. As soon as the airplane is clear of the ground and obstructions, the power should be adjusted to the climb conditions.

When reducing engine power on installations having constant speed propellers, the manifold pressure is always reduced first by use of the throttle, and then the propeller speed is reduced. A good procedure is to reduce the manifold pressure and then the propeller speed in successive alternate steps of approximately 2 in. Hg and then 200 rpm until the desired power is attained. When increasing the engine power the propeller speed should always be increased first and then the manifold pressure.

With a two-position propeller the climb may be made in either "high" or "low" pitch. The most common practice is to shift into the "high pitch" (low rpm) when well clear of the ground and make a gradual climb. An alternate method would be to climb rapidly to the cruising altitude in "low pitch" (high rpm).

As altitude increases, it will be necessary to open the throttle gradually to maintain the same manifold pressure.

If there is a tendency for the oil to overheat with the oil-cooler shutters full open, it may be checked by reducing the engine speed with the propeller control, rather than by throttling alone.

After the climb the engine should be given a chance to cool down before the mixture control is changed to the lean position. It is preferable to allow cooling even below the final cruising temperatures. This permits the induction system as well as the cylinders to cool down. A well-cooled engine will have less tendency to detonate and overheat pistons as the mixture is leaned than will an engine where the cylinder temperatures are at the maximum permissible for cruising.

In installations having carburetors with automatic mixture control the "automatic lean" position is used for normal cruising operation. If the mixture is manually controlled and a constant speed propeller is used, an exhaust gas analyzer should be used as a guide when adjusting the mixture control. The analyzer will be marked for proper fuel-air ratio to be used at various power outputs. Changes in air density will affect the fuel-air ratio, so the analyzer should be watched and the mixture control adjusted as necessary to maintain the proper mixture.

On installations where the mixture is manually controlled and a fixed-pitch or two-position propeller is used, the mixture may be adjusted by noting the change in engine rpm. While the mixture control is being moved from the rich position toward the lean position, the position at which the rpm begins to decrease should be noted. The point

at which the rpm begins to drop is commonly called the *lean best power.* This setting may be used for cruising outputs up to approximately 65 per cent of normal rated power.

During cruising it often happens that fuel tanks are allowed to run dry before the supply is shifted to another tank. When constant speed propellers are in use, the propeller will shift to the low pitch position as the engine loses power in an effort to maintain the rpm. After the fuel supply is again established the engine picks up power and, with the propeller in the low pitch position, overspeeding occurs until the propeller has sufficient time to change pitch. This overspeeding may be injurious to the engine, especially at high altitudes where high rpm may be attained. It is, therefore, good practice to reduce the throttle setting in the event that a tank runs dry and then readjust after the fuel supply is reestablished.

If any emergency arises which necessitates using a power greater than normal cruising power in installations using constant speed propellers, the propeller control should first be adjusted to give an increase in rpm and then the throttle should be adjusted to give an increase in the manifold pressure. In general, between the limits of normal cruising power and normal rated power, the variations in manifold pressure and rpm should be proportionate.

During normal cruising operation, maximum engine efficiency and, as a rule, propeller efficiency are attained by operating with power reduced by lowered engine speed rather than by reduced manifold pressure with a high engine speed. This, of course, is only possible with installations using constant speed propellers. The manifold pressure may be maintained at the maximum permitted for cruising at critical altitude and the power reduced by reducing the engine speed. This type of power control, usually called the constant B.M.E.P. cruising procedure, results in minimum fuel consumption and is particularly useful in long range operation and airline service. Its chief benefit is derived from the reduced friction and supercharger horsepower at low engine speeds. Lower operating temperatures of cylinders and oil usually accompany this method of control.

During a cruise descent the operation is the same as for level cruise. It will be necessary to close the throttle gradually during descent to maintain the same manifold pressure.

When approaching for landing, controls should be placed in position for take-off horsepower, which it may be necessary to use in the event of overshooting the field or other emergency. If the propeller control is set for the rpm of normal rated power rather than that of take-off power, it will permit a more rapid opening of the throttle with-

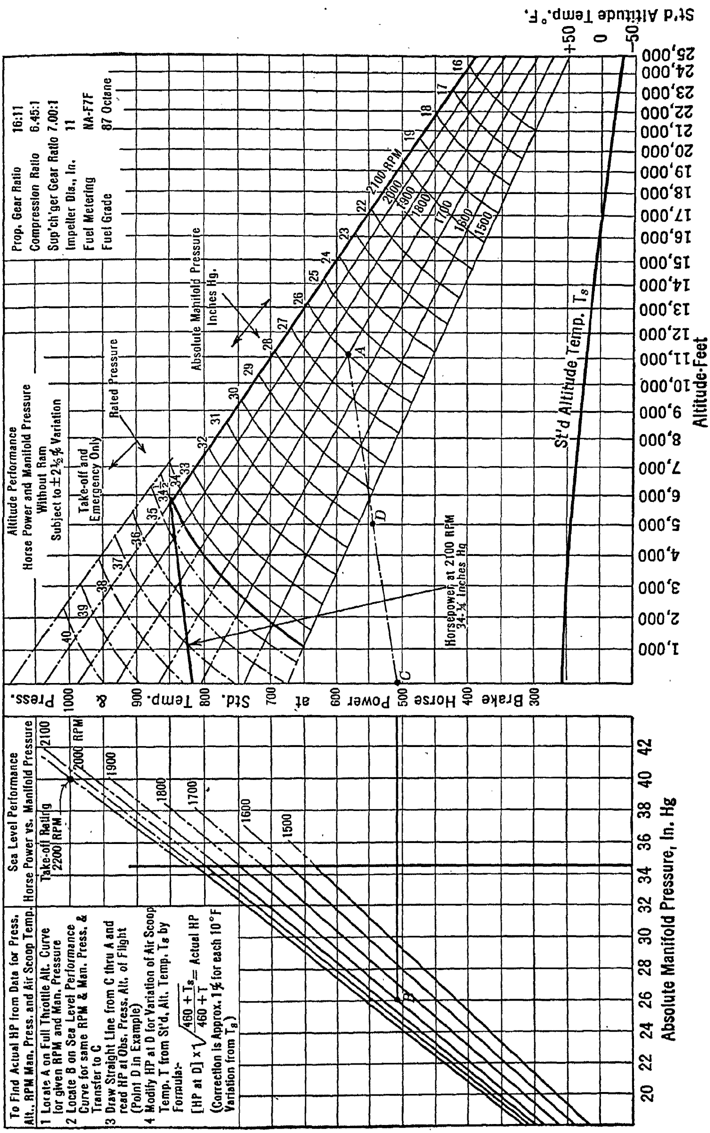
out danger of serious overspeeding. This rpm will allow the engine to develop normal rated power or more for emergency operation, and full take-off power will be made available by moving the propeller control to take-off rpm after the throttle has been opened.

Use of Power Charts. Other conditions remaining constant, the horsepower output of an engine is very closely proportional to its mass (weight) air consumption. The mass air consumption of an engine is governed by the cylinder inlet pressure, the inlet air density, the amount of residual gases left in the combustion chamber, and the number of suction strokes per unit of time. The amount of residual gases left in the combustion chamber is a function of the outside air pressure at the exhaust ports. In addition to the effect on scavenging the outside pressure at the exhaust ports also affects the engine pumping losses, the losses becoming less as pressure decreases. To simplify the calculations, outside air pressure is usually measured in terms of *pressure altitude.* A pressure altitude of 0 ft (sea level altitude) is actually a pressure of 14.7 lb per sq in. abs. As pressure altitude increases the magnitude of the actual pressure decreases.

The manifold pressure, the rpm, the pressure altitude, and the inlet air temperature (temperature and pressure determine density) being known, it is possible to calculate the horsepower output of an engine. There is illustrated in Fig. 258 a typical power chart from which engine output may be quite accurately estimated by using these four instrument readings. It is, of course, necessary to use a chart constructed especially for the engine concerned.

The chart is divided into two parts, one for sea level conditions and the other for altitude conditions. Under standard sea level conditions (29.92 in. Hg barometric pressure and 60°F carburetor intake air temperature), power may be read directly for any rpm and manifold pressure by using the sea level portion of the chart. According to the chart, the power output at 26 in. Hg manifold pressure and 1800 rpm (point *B*) is 510 hp at standard sea level conditions. Should the carburetor intake air be at some temperature other than the standard of 60°F, it will be necessary to make a correction for the difference. A quick and fairly accurate correction may be made by adding 1 per cent to the horsepower for every 10°F of temperature deviation below standard temperature and subtracting 1 per cent for every 10°F above standard temperature. For example, if the carburetor intake air temperature were 100°F there would be a deviation of 40° (100° − 60°) above standard, which would necessitate subtracting 4 per cent from 510 hp, giving 489.6 hp (510 − 20.4).

The sea level portion of the chart is useful in determining power at



Courtesy Wright Aeronautical Corporation

FIG. 258. Typical engine power chart.

or near sea level and it assists in power determination at altitude.

For conditions where the atmospheric pressure is below 29.92 in. Hg, power is determined from the altitude power chart. Air pressure on this chart is expressed as feet altitude rather than as inches Hg or pounds per square foot. When reading the feet altitude, the altimeter zero or barometer setting should be 29.92 in. Hg in order to indicate the correct feet altitude pressure.

The curves on the altitude power chart are drawn for standard conditions at each altitude; that is, where the temperature is standard for each pressure altitude. The standard temperature for any pressure altitude may be read from the "standard altitude temperature" line at the bottom of the chart. The power correction, as previously mentioned, may again be used when carburetor intake air temperatures vary from "standard temperature" at any altitude.

The rpm lines on the chart which extend from sea level to 25,000 ft represent the full throttle power of "standard altitude," with neither ram pressure nor restriction in the carburetor air intake. The lines crossing the rpm lines are the manifold pressures necessary to obtain the full throttle power at each altitude.

In the example determination, shown on the chart, with 1800 rpm and 26 in. Hg, full throttle power is obtained at 11,100 ft and is 585 hp (point *A*). This is more horsepower than that obtained at sea level (510 hp) with the same manifold pressure and rpm. This increase in power at altitude is accounted for by the reduction in back-pressure on the exhaust system. By drawing a line (*AC*) connecting the points of full throttle power obtained at altitude (point *A*) and the partial throttle power obtained with the same rpm and manifold pressure at sea level (point *C* carried over from point *B*), we will have a line representing the variation in power with change in altitude when maintaining constant rpm and constant manifold pressure. The partial throttle power at, for example, 5000 ft, using 26 in. Hg manifold pressure and 1800 rpm, is 545 hp (point *D*), provided the carburetor intake air temperature agrees with the "standard altitude temperature." If the temperature does not agree the correction as previously mentioned will have to be made.

When the carburetor air intake scoop faces into the slip stream, a certain amount of ram pressure is obtained at the carburetor. This ram pressure has a supercharging effect which raises the altitude at which full throttle manifold pressure may be obtained. However, this ram effect will not affect the partial throttle calculations.

Several types of power charts may be derived from the one just discussed to meet particular operating requirements.

CHAPTER XIV

INSPECTION, SERVICE, AND REPAIR

The periodic inspection and service of the power plant constitute the fundamental principle of maintenance. It is only through this periodic inspection and service that the continued proper operation of the power plant may be maintained.

The period, or elapsed flying time, at which the various items of inspection and service should be performed are established through service experience. It will, of course, be appreciated that these periods will change with changes of engine operating conditions and will differ with different equipment. It is, therefore, not possible to establish definite periods at which various engines operating under varying conditions should have particular items inspected and particular services performed. Therefore, the following periods of inspection and the services to be performed at each period are offered as a guide rather than as definite procedure. The definite periods and the services to be performed will have to be established by the particular operator. In all instances, the recommendations of the engine and accessory manufacturers should be consulted. It may be said, however, that the following procedure closely follows that of the commercial air lines, whose engines are operated under very favorable conditions, and use little more than 50 per cent rated power for cruising conditions.

When power plants are inspected and serviced a printed form should be used for listing the various routine items and spaces should also be provided for listing extra items which inspection may reveal as necessary. As far as practicable the items should be listed in the order in which it is most convenient to perform them. A definite procedure should be established for checking the items as they are performed. Such a procedure may utilize symbols to indicate the extent of work which was necessary and the completeness with which it was performed.

It will be noted in the following inspection lists that very little is said concerning the method of performing the various items. The method has been discussed under appropriate headings throughout this book.

Each successive periodic inspection includes all items of previous, shorter inspection periods as well as the items of the particular inspec-

tion period. For instance, the 100-hr inspection period includes all items of the daily or preflight, 25-hr and 50-hr, as well as the 100-hr, inspection items. The routine commences again after the longest inspection period.

DAILY OR PREFLIGHT INSPECTION

1. Check quantity of fuel and oil. Make certain that tank caps and measuring rods are locked in place.

2. Drain fuel sumps, fuel tank sumps, and the lowest point in the system. Safety-drain cocks after closing.

3. Turn Cuno oil cleaner. If the automatic-type cleaner is installed, its operation may be checked by observing the rotation of the manual operating shaft while the engine is being run up. A piece of masking tape stuck on the operating shaft aids in detecting the rotation. Oil strainers of newly installed engines should be removed and cleaned after the adjustment run-up and again after the test flight.

4. Check quantity of radiator fluid. If a liquid-cooled engine, see that the radiator is filled to the proper level. Lock radiator cap or plug in place.

5. Inspect cowling for proper fastening. Excessive tightness of turnbuckles and other cowling fastening devices when the engine is cold is likely to cause failure of the attachments when the engine becomes heated and expands. Fastenings should be drawn up snug but not tight while the engine is cold.

6. Inspect propeller blades and hubs. Inspect for nicks or scratches on blades, looseness on propeller shaft, looseness of blades in hub, proper safetying of all exposed parts, oil leakage, and proper installation of spinners if installed.

7. Lubricate propeller counterweights. Wipe metal blades and hub with an oil-saturated cloth.

8. Lubricate manually lubricated valve mechanisms. Best flow of the lubricant will result if lubrication is done while the engine is still warm. Approximately five " shots " with a hand push grease gun are sufficient. If each cylinder's piston is at approximately top center during its servicing, the tension will be relieved on the rocker arm and will assure better distribution of lubricant about its bearing.

9. Lubricate exhaust-driven superchargers. While spinning the turbine by hand add lubricant with grease gun. A slowing down of the turbine indicates a sufficiency of lubricant.

10. Check operation of all controls. This check should cover the freedom of movement, the degree of movement, and slack in the controls.

11. Check engine instruments. Check for proper pointer positions and broken or loose cover glasses. Clean cover glasses. Check instrument lighting.

12. Check fuel pressure warning signal. Raise pressure with auxiliary fuel pump.

13. Inspect fire extinguisher valve. Ascertain that system has not been discharged.

GROUND RUN-UP

14. Check oil pressure warning signal. As oil pressure builds up check pressure at which warning light goes out.

15. Check fuel valves. Check operation on all fuel tanks. Set valve on proper tank for take-off by "click and feel."

16. Check propeller operation. Check operation of controllable-pitch propellers.

17. Check engine instruments. Check for proper instrument operation, consistency of indication with engine operation requirements, and excessive pointer oscillation.

18. Check ammeter reading. If ammeter is not registering, apply load to electrical circuit.

19. Check engine output. For both the magneto check and engine output check, constant speed propeller governors must be in the high rpm (take-off) position so that the propeller will remain in full low pitch in order that the engine rpm will vary with engine output. The normal rpm for a given manifold pressure or throttle opening must be established for each type of engine installation.

20. Check magnetos. Check drop in rpm while operating on each magneto singly.

21. Test supercharger clutch. If engine is equipped with a two-speed supercharger test the clutch for proper operation.

22. Drain manifold pressure gauge line. Allow drain valve to remain open 10 to 15 sec with the engine idling.

25-HOUR INSPECTION PERIOD

23. Remove cowling. Remove sufficient cowling to inspect controls, piping, exhaust and intake systems, and accessories.

24. Inspect all controls. Inspect for travel, operation, and security of installation.

25. Inspect all piping. Inspect tubing, connections, and bonding. Raise fuel pressure with auxiliary pump and check for leaks.

26. Inspect bolts and nuts. Visually inspect all engine and engine mount nuts and bolts.

27. Inspect exhaust system. Check for loose or cracked joint clamps, cracked and leaking tubes, and security of mounting.

28. Inspect accessory brackets. Inspect all accessory brackets and mountings for cracks and security of installation.

29. Inspect motor mount for cracks.

30. Remove Cuno oil strainer and clean.

31. Grease fuel pump, if externally lubricated pump is installed.

32. Inspect oil tank. Check vent opening if not vented to engine. Check for leaks and security of mounting, paying particular attention to the mounting pads.

33. Inspect oil cooler for leaks.

34. Inspect radiator of liquid-cooled engines. Check for leaks at radiator and expansion tank. Check security of mounting and operation of shutters.

35. Inspect ignition harness and conduit. Check for tightness of connector nuts and chafing of conduit.

36. Remove and clean fuel strainers.

37. Grease coolant liquid pump (liquid-cooled engines only).

38. Inspect coolant liquid pump for leaks.

39. Inspect primer and connections for leaks.

40. Clean vacuum pump exhaust line.

50-HOUR INSPECTION

41. Remove all power plant cowling.

42. Clean complete power plant unit. Using a spray with compressed air and mineral spirits is a very good method of cleaning engines. Care must be taken not to direct the spray in such a manner that it will saturate electrical cables or wash the lubricant from control rod and other grease-lubricated bearings.

43. Inspect cowling. Repair cowling as necessary. Replace worn mounting pads.

44. Remove rocker box covers. This is necessary only for manually lubricated valve mechanisms. Clean rocker boxes and replace with fresh lubricant. Check and adjust valve clearances. Inspect the complete mechanism within the rocker box. Grease ball ends of push rods. It is good practice to check the valve clearances of automatically lubricated valve mechanisms at the first 50- or 100-hr inspection after installation.

45. Check push rod packing nuts. Check tightness of hose clamps if hose connections are used. Tighten as necessary.

46. Check intake pipe packing nuts. Tighten as necessary. Excessive tightening will neck the pipes, as they are made of soft metal.

47. Inspect exhaust manifold for " blown " gaskets. Check tightness of exhaust stud flange nuts.

48. Inspect cylinder baffles. See that the baffles and attaching brackets are free from cracks and are mounted securely. Make sure that the brackets have not worn into the cylinder barrels.

49. Check cylinders for leaks. With all spark plugs installed pull the propeller through slowly while listening for air leaks. Loose or leaking cylinder heads may be detected by deposits of escaped oil.

50. Check thrust bearing nut for tightness.

51. Check all accessory mounting nuts for tightness.

52. Check engine mounting bolts for tightness.

53. Inspect vibration-absorbing elements.

54. Inspect visually all bolts and nuts. All bolts and nuts not specifically designated to be checked for tightness should be visually inspected for tightness and safety. Look for oil leaks, as they are likely to indicate looseness of nuts or other connections.

55. Drain oil sump. Remove and clean all engine oil strainers.

56. Drain and flush cooling system (liquid-cooled engines only).

57. Clean carburetor strainer. Drain float chamber.

58. Lubricate carburetor external working parts.

59. Inspect carburetor for leaks. Inspect all connections, parting surfaces, plugs, and their safeties.

60. Check carburetor mounting nuts.

61. Inspect carburetor intake and heater manifolds.

62. Check fuel pump vent opening.

63. Inspect hydro-controllable propeller governor. Inspect for external oil leaks around governor base and head. Check connections and mounting.

64. Lubricate propeller blade bearings.

65. Inspect electric propeller slip ring assembly. Inspect brushes for wear and tension of brush springs. Clean oil and carbon from brushes, brush holder, and slip rings.

66. Inspect electric propeller relay points.

67. Check action of electric propeller limit switch.

68. Check operation of electric propeller brake.

69. Clean cartridge starter breech barrel. Use penetrating oil and cotton swab, or special cleaning solution.

70. Lubricate engine controls where necessary.

71. Inspect thermocouple connections. Examine thermocouple leads and connections for breakage and tightness.

72. Check flexibility and mounting of instrument board.

73. Check manifold pressure gauge reading.

74. Check zero setting of electrical instruments.

75. Weigh carbon dioxide fire extinguisher cylinder. This need be done only at the first 50-hr inspection after installation. If no leakage is evident, subsequent inspection by weighing need be made only at 6-month intervals.

100-HOUR INSPECTION

76. Check compression of each cylinder. With at least one spark plug removed from all of the cylinders except the one being checked, the compression may be fairly well checked by pulling the propeller through by hand. A more accurate method is to install a pressure gauge, preferably a special compression gauge with check valve in inlet, in place of the front spark plug.

77. Check cylinder hold-down nuts. It is good practice to check the cylinder hold-down nuts with a torque wrench at the first 50- or 100-hr inspection after installation.

78. Check tappet retaining nuts.

79. Check engine breather screen for cleanliness.

80. Drain oil system and refill.

81. Replace spark plugs.

82. Remove magneto breaker cover. Clean and inspect breaker compartment. Inspect breaker points. Lubricate cam follower as necessary.

83. Check electrical connections. Open all junction boxes.

84. Lubricate electric propeller speed reducer.

85. Service exhaust gas analyzer.

86. Inspect generator brushes and wiring.

87. Inspect control box regulator points.

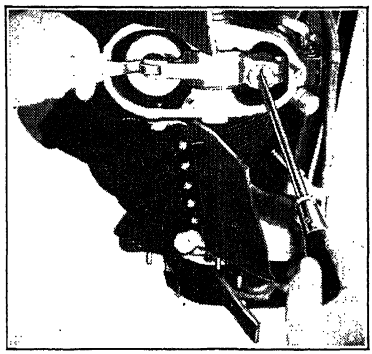
88. Disassemble cartridge breech. Disassemble only sufficiently to thoroughly clean breech.

CHECKING VALVE CLEARANCES

After the rocker box covers and at least one spark plug from each cylinder have been removed, the engine is turned in its normal direction of rotation until No. 1 piston is at the top dead center position on the compression stroke. In this position both valves are completely closed and have the maximum cold clearance. The correct cold clearance will be found on the engine data plate. A feeler gauge, corresponding in thickness with the correct cold clearance, is inserted between the top of the valve and the rocker arm. The valve-adjusting screw lock nut or lock screw is unlocked, and the screw is adjusted until the feeler

gauge may be removed with a slight pull. The adjusting screw lock nut, or lock screw, is then tightened snugly. Care must be taken not to turn the adjusting screw while tightening the lock nut. After the lock nut is tightened, the clearance of the valve should again be checked.

The adjusting screw of some valve mechanisms with automatic lubrication, if locked in certain positions, will allow oil under pressure to discharge from oil holes in the adjusting screw directly into the rocker box instead of passing through the rocker arm bearing. Such adjusting screws must not be left with the oil holes in line with the slot in the rocker arm. The positions of the oil holes are marked on the head of the adjusting screw and if, at adjustment, any hole should align with the slot, the adjusting screw should be turned the shortest possible distance to correct this condition.



Courtesy Wright Aeronautical Corporation

FIG. 259. Checking valve clearance.

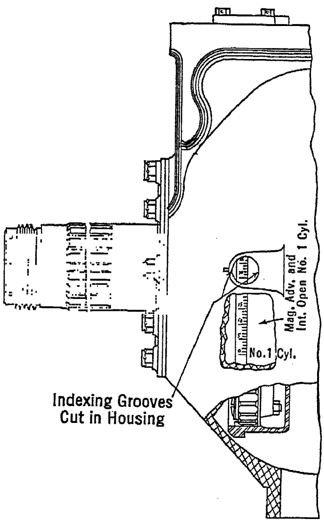
After the valves of No. 1 cylinder have been adjusted, the valves of the remaining cylinders are adjusted in the same manner, making sure that the pistons are at the exact top dead center of their respective compression strokes and following the firing order of the engine. The firing order of the cylinders will be found on the engine data plate. For a single-row nine-cylinder radial engine the firing order is 1–3–5–7–9–2–4–6–8. For a twin-row fourteen-cylinder radial engine it is 1–10–5–14–9–4–13–8–3–12–7–2–11–6. It is imperative that each piston be at the top dead center of the compression stroke when the valves are adjusted.

After all the valves have been adjusted, the crankshaft is turned two complete revolutions and the clearances checked again. Any clearance which is less than the feeler gauge thickness should be readjusted. Any clearance that is found to be more than the feeler gauge thickness in the new position should be disregarded and the original adjustment retained. The reason that there may be a difference in the clearances after the crankshaft is turned is that the cam rollers are between different cam lobes each time the crankshaft is turned two revolutions. This would not be true on an in-line engine where each valve has its own cam lobe, which makes a complete revolution each two crankshaft revolutions.

After the final valve adjustment the rocker box covers are reinstalled. Rocker box cover gaskets are replaced where necessary. Oil leakage will result if the gaskets are not in good condition. If rocker box covers should be distorted, they may be refaced by lapping them on a surface plate with a coarse lapping compound.

TIMING

For timing magnetos and valves it is necessary to have some method of establishing the exact top dead center of at least one of the cylinder pistons, usually the No. 1 cylinder, and of measuring the crankshaft angular position to either side of the top dead center position. Valves are timed at overhaul and unless some portion of the valve gear train is removed there will be no necessity for valve timing after overhaul.



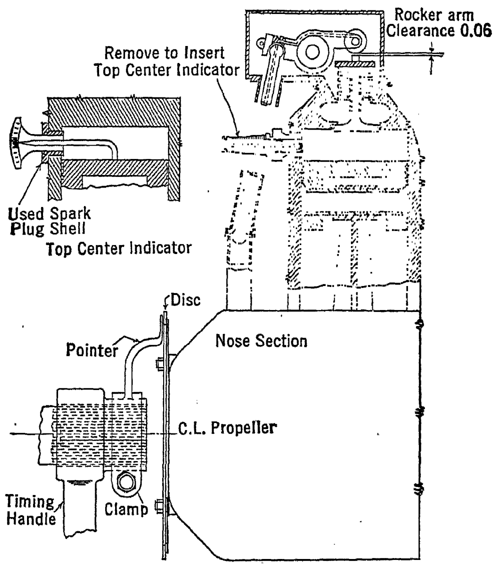
Courtesy Wright Aeronautical Corporation

FIG. 260. Timing marks on reduction driving gear.

Some engines with reduction gears have a timing scale marked on the reduction driving gear. On such engines, magneto timing is very much simplified. By removing the plug from the timing hole in the front section the timing marks may be viewed, as illustrated in Fig. 260. The propeller shaft is turned in the normal direction of rotation until the "0" of No. 1 cylinder, as indicated by the markings on the driving gear, lines up with the pointer while the No. 1 piston is on top of the compression stroke. The propeller shaft is then turned still farther until the full advance firing position of No. 1 cylinder, given on the engine data plate, is indicated on the reduction driving gear timing scale.

When timing a geared engine that does not have the above reduction driving gear timing scale, it must always be remembered that the propeller shaft of a geared engine does not turn at the same rate as the crankshaft, but always at a slower rate. Therefore, if the propeller shaft is turned a certain number of degrees the crankshaft will turn more than that number of degrees, the amount depending upon the reduction gear ratio.

With the piston at or near top dead center there is very little motion of the piston in relation to crankshaft rotation. For this reason it is not so easy to establish the exact top dead center of the piston. The more accurate method is to measure the angular position of the crankshaft when the piston is a certain distance below top dead center on both the upstroke and downstroke. Then, by taking the angular midposition of the crankshaft, between the two positions at which the crankshaft was when the piston was the same distance down from top dead center, the top dead center position is established.



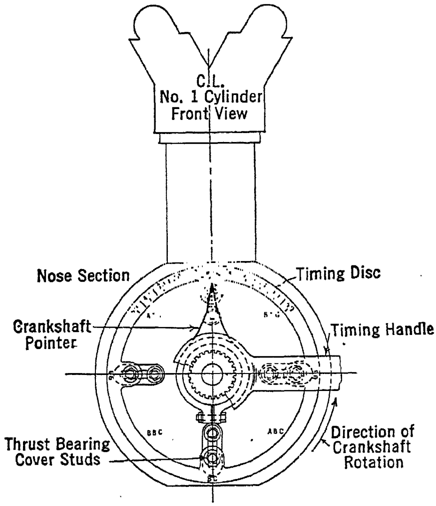
Courtesy Civil Aeronautics Administration

FIG. 261. Side view of radial engine timing method.

For carrying out the above procedure the top center indicator, timing handle, pointer, and timing disc, as illustrated in Figs. 261 and 262, or equivalent equipment, are required.

After the equipment has been installed, the crankshaft is turned in the normal direction until the piston contacts the top center indicator on the compression stroke. While the piston is still well below top center, the position of the top center indicator pointer is marked. The position of the pointer on the timing disc is also marked. Now the crankshaft is turned until the piston reaches top center and continues on the downstroke until the top center indicator pointer reaches the position previously marked. The position of the pointer on the tim-

ing disc is observed. If, now, the number of degrees the pointer has moved across the timing disc is halved and the crankshaft is turned backwards that number of degrees the piston will be at exact top dead center. With the piston on top dead center the crankshaft pointer, or



Courtesy Civil Aeronautics Administration

FIG. 262. Front view of radial engine timing method.

timing disc, or both may be adjusted so that the pointer lines up with the zero degree (top dead center) marking on the timing disc. The crankshaft may then be rotated the required number of degrees for the magneto timing.

CYLINDER REMOVAL AND REPLACEMENT

Worn, sticking, and broken piston rings, leaking valves, and other troubles often make it necessary to remove and replace or repair cylinders and pistons.

Assuming that all obstructing cowling and brackets have been removed, the first step is to remove the intake and exhaust pipes. Any cylinder baffles and attaching brackets which would obstruct the cylinder removal may then be removed. Spark plugs are also removed.

Rocker box covers are removed. Push rod packing gland nuts or hose clamps, top and bottom, are loosened. The push rods of some engines may be removed by depressing the rocker arms, and other engines require removal of the rocker arms before the push rods may be removed. Before the push rods are removed, the crankshaft is

turned until the piston is at top dead center on the compression stroke. This relieves the pressure on both the intake and exhaust rocker arms and allows maximum clearance for the push rod removal when the rocker arms are depressed. If the push rod cannot be readily removed with the valve fully depressed, more clearance may be obtained by backing off on the rocker arm adjusting screw.

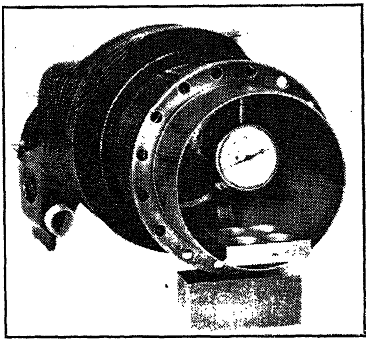
As the push rods are removed they should be marked so that they may be replaced as they were before removal. This is because the ball ends have worn to fit the sockets in which they have been operating. A good procedure is to mark the push rods near the valve tappet ends as follows: "1 In," "1 Ex," "2 In," "2 Ex," etc.

All cylinder hold-down nuts or cap screws are removed. The cylinder is pulled gently away from the crankcase. After the cylinder skirt has cleared the crankcase and before the piston protrudes from the skirt, the crankcase cylinder hole is stuffed thoroughly with clean rags. This will prevent any pieces of broken piston rings from falling into the crankcase. The rags should be so arranged that they may be removed without the possibility of any trapped particles entering the crankcase. After the piston has been removed the rags should be removed and cleared of any ring pieces. As a check to make certain that no ring pieces have entered the crankcase, all pieces should be collected and arranged to see that they form the required number of complete rings.

If a master rod cylinder is to be removed, its piston must be at top dead center. Arrangements must be made to hold the master rod in the midposition of the crankcase cylinder hole. This may be done by use of the rags used to close the hole. Before rags are removed, the master rod must be blocked or wired so that it will remain in the midposition. Under no circumstances turn the crankshaft. These precautions are necessary so as not to allow the bottom rings on some of the other pistons to come out of the cylinders and seriously damage the piston, piston ring, and skirt of these cylinders. If several cylinders are to be removed, of which the master rod cylinder is one, the master rod cylinder should always be removed last and it should be the first installed. Master rods are usually in the top cylinder but may be in any cylinder. The engine manual should be consulted. Some engines have an "M" marked on the flange of the cylinder carrying the master rod.

To remove the piston pin it may be necessary to use a drift or special screw jack removing tool. The piston pin is a push fit at room temperature and if difficulty is encountered in pushing it out the piston be slightly heated with a torch to loosen it. If a drift is used in

removing the piston pin the connecting rod should be supported so that it does not take the shock of the blows. If this is not done the connecting rod may be damaged.

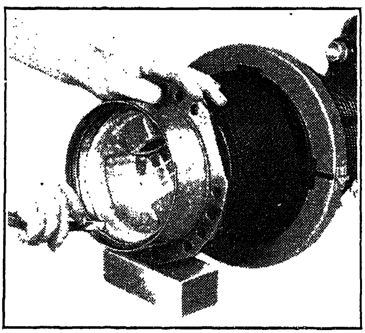


Courtesy Pratt and Whitney Aircraft

FIG. 263. Checking the cylinder barrel for wear and out-of-round.

FIG. 264. Checking piston ring side clearance.

For the overhaul of a cylinder the engine manufacturer's overhaul manual should be consulted, as it is only there that the details of construction, the limits on wear, the correct angles of valve and seat faces, the piston ring clearances, and other pertinent information can be found.



Courtesy Wright Aeronautical Corporation

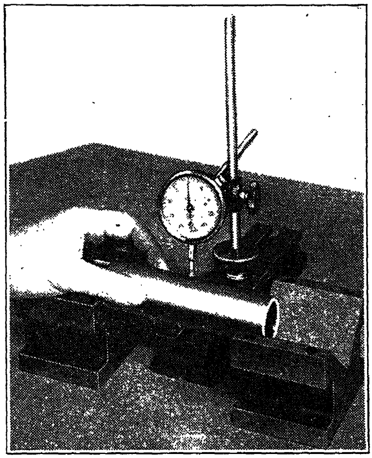
FIG. 265. Checking piston ring end clearance.

FIG. 266. Piston ring removal and installation tool.

Before installing a new piston the piston ring clearances should be checked unless it is definitely known that they have been previously checked for the cylinder with which they are to be used. Some radial

engines require different clearances for the rings of different cylinders. Some engines also use a different type of piston in the lower cylinders. To make certain of these points and of the piston ring arrangement the manufacturer's overhaul manual and service bulletins should be consulted.

If necessary to install a new piston and ring assembly or a new cylinder it is recommended that the piston rings be lapped in their respective cylinders with a dummy or scrap piston. A fine valve lapping compound (Clover 2A), diluted with a little kerosene and oil, should be used. The number of lapping strokes necessary may be judged by the surface of the piston rings. They should be lapped until the original tool marks on the outside surface have practically disappeared and the surface assumes a smooth satin finish around the periphery of the ring. During the lapping, the valves should be in place in the cylinder, and during the subsequent washing operation, the cylinder should be held in the vertical position and every effort should be made to remove all traces of the lapping compound without permitting any of it to be washed up into the head of the cylinder.



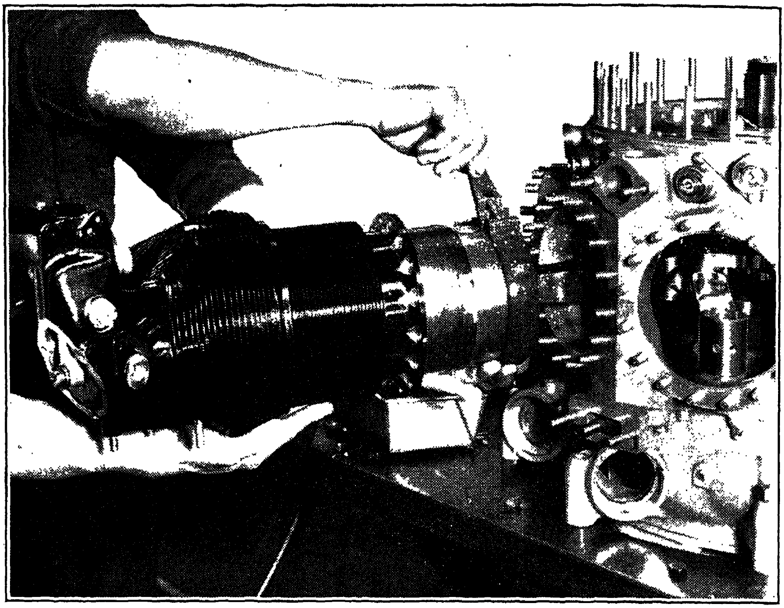
Courtesy Wright Aeronautical Corporation

FIG. 267. Testing the alignment of a piston pin.

Before installing the piston pin, its alignment may be checked by the use of V-blocks and a micrometer dial indicator. The piston pin should be coated with engine oil before assembling.

Before the cylinder is installed, the inside of the cylinder barrel and the piston ring assembly are coated generously with engine oil. One should be sure that the cylinder oil seal ring is in place on the cylinder skirt and that only one ring is used. With the aid of a piston ring clamp as shown in Fig. 268, the cylinder is slid over the piston and into place. Stud nuts or cap screws are installed and tightened snugly with cylinder hold-down wrench; an ordinary wrench handle is used. The nuts should be tightened evenly about the circumference, going from one nut to a diametrically opposite nut each time. After all nuts have been tightened snugly, they should be drawn up to the proper tension, using a torque wrench in place of the ordinary wrench handle.

The installation of the push rods, push rod housings, and intake pipes, etc., is practically the reverse of their disassembly. New gaskets are used where necessary. After installation of the push rods the valve clearances are adjusted. Some engine oil is sprayed into the rocker boxes and around valve stems, if the valve mechanism is automatically



Courtesy Pratt and Whitney Aircraft

FIG. 268. Installation of cylinder using a piston ring compressor.

lubricated; the rocker box is filled with lubricant if not automatically lubricated. Rocker box covers are replaced.

If it has been necessary to install a new piston and ring assembly or a new cylinder, the engine should be given a ground run of several hours to seat the piston rings further.

APPENDIX

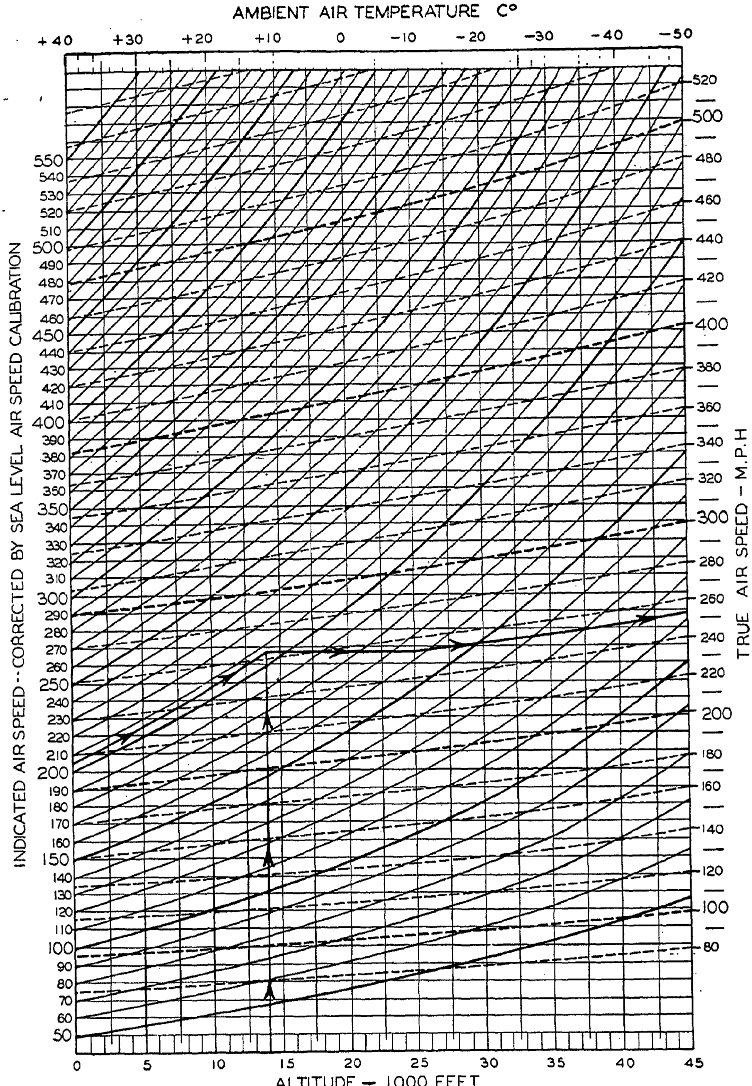
STANDARD ALTITUDE DATA

Altitude Ft	Temp. °F	Abs Temp. °F	$\frac{\rho}{\rho_0}$	Pressure In. Hg	Horsepower Corr. Factor
0	59.000	518.400	1.0000	29.92	1.000
500	57.217	516.617	0.9855	29.38	0.984
1000	55.434	514.834	0.9710	28.86	0.967
1500	53.651	513.051	0.9568	28.33	0.951
2000	51.868	511.268	0.9428	27.82	0.935
2500	50.085	509.485	0.9288	27.31	0.920
3000	48.301	507.701	0.9151	26.81	0.904
3500	46.518	505.918	0.9015	26.32	0.889
4000	44.735	504.135	0.8881	25.84	0.874
4500	42.952	502.352	0.8748	25.36	0.859
5000	41.169	500.569	0.8616	24.89	0.844
5500	39.386	498.786	0.8487	24.43	0.829
6000	37.603	497.003	0.8358	23.98	0.814
6500	35.820	495.220	0.8232	23.53	0.800
7000	34.037	493.437	0.8106	23.09	0.786
7500	32.254	491.654	0.7982	22.65	0.772
8000	30.471	489.871	0.7859	22.22	0.758
8500	28.688	488.088	0.7738	21.80	0.744
9000	26.904	486.304	0.7619	21.38	0.730
9500	25.121	484.521	0.7501	20.98	0.717
10000	23.338	482.738	0.7384	20.58	0.704
10500	21.555	480.955	0.7269	20.18	0.691
11000	19.772	479.172	0.7154	19.79	0.678
11500	17.989	477.389	0.7042	19.40	0.665
12000	16.206	475.606	0.6931	19.03	0.652
12500	14.423	473.823	0.6821	18.65	0.640
13000	12.640	472.040	0.6712	18.29	0.627
13500	10.857	470.257	0.6605	17.93	0.615
14000	9.074	468.474	0.6499	17.57	0.602
14500	7.291	466.691	0.6394	17.22	0.591
15000	5.507	464.907	0.6291	16.88	0.580
15500	3.724	463.124	0.6189	16.54	0.568
16000	1.941	461.341	0.6088	16.21	0.556
16500	0.158	459.558	0.5988	15.89	0.546
17000	−1.625	457.775	0.5891	15.56	0.535
17500	−3.408	455.992	0.5793	15.25	0.524
18000	−5.191	454.209	0.5698	14.94	0.513
18500	−6.974	452.426	0.5603	14.63	0.503
19000	−8.757	450.643	0.5509	14.33	0.492
19500	−10.540	448.860	0.5418	14.04	0.482
20000	−12.323	447.077	0.5327	13.75	0.471
20500	−14.106	445.294	0.5237	13.46	0.461
21000	−15.890	444.510	0.5148	13.18	0.451
21500	−17.673	441.727	0.5061	12.90	0.441
22000	−19.456	439.944	0.4974	12.63	0.430
22500	−21.239	438.161	0.4889	12.36	0.421
23000	−23.022	436.378	0.4805	12.10	0.411
23500	−24.805	434.595	0.4721	11.84	0.402
24000	−26.588	432.812	0.4640	11.59	0.393
24500	−28.371	431.029	0.4559	11.34	0.384
25000	−30.154	429.246	0.4480	11.10	0.375
25500	−31.937	427.463	0.4401	10.86	0.366
26000	−33.720	425.680	0.4323	10.62	0.357
26500	−35.504	423.896	0.4247	10.39	0.349
27000	−37.287	422.113	0.4171	10.16	0.340
27500	−39.070	420.330	0.4097	9.939	0.332
28000	−40.853	418.547	0.4023	9.720	0.323
28500	−42.636	416.764	0.3951	9.504	0.315
29000	−44.419	414.981	0.3879	9.293	0.307
29500	−46.202	413.198	0.3809	9.085	0.299
30000	−47.985	411.415	0.3740	8.880	0.291
30500	−49.768	409.632	0.3671	8.680	0.284
31000	−51.551	407.849	0.3603	8.483	0.276
31500	−53.334	406.066	0.3537	8.290	0.269
32000	−55.117	404.283	0.3472	8.101	0.261
33000	−58.684	400.716	0.3343	7.732	0.246
34000	−62.250	397.150	0.3218	7.377	0.232
35000	−65.816	393.584	0.3098	7.036	0.229

AIR SPEED CHART

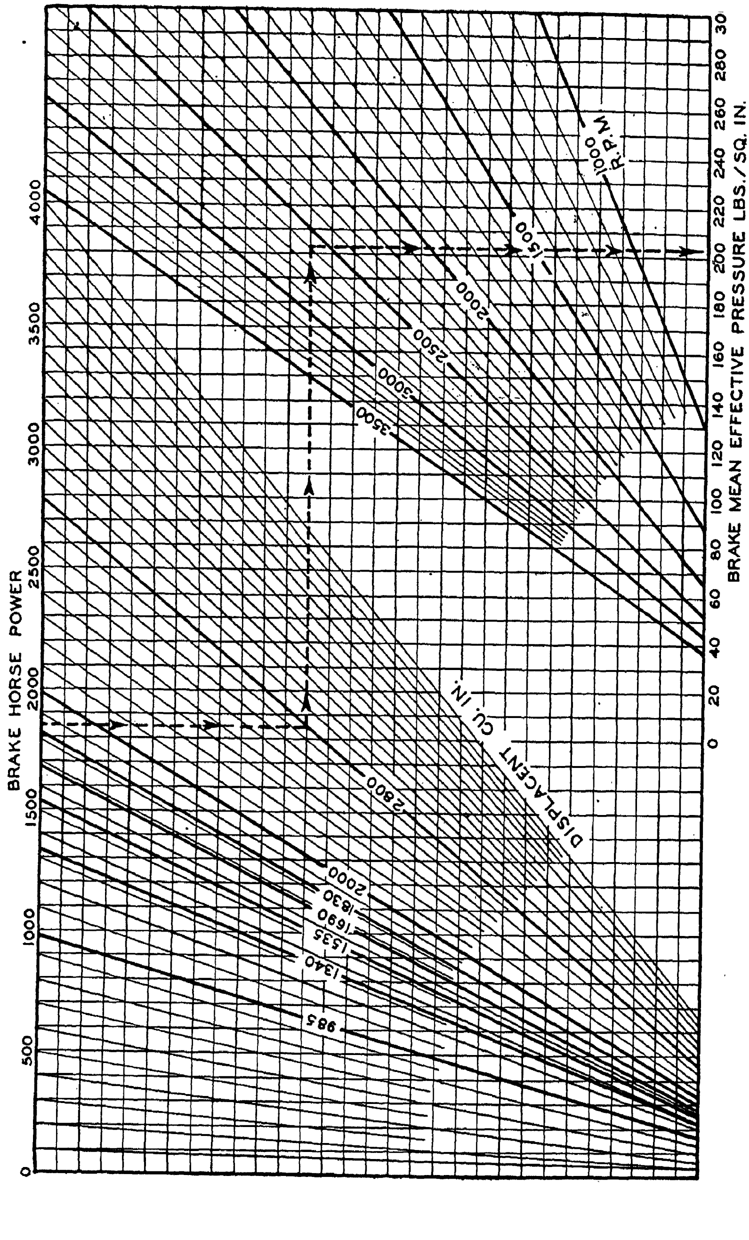
(Including compressibility factor at altitude)

EXAMPLE: Indicated air speed = 205 mph at 14,000 ft and −10° C. True air speed = 252 mph.



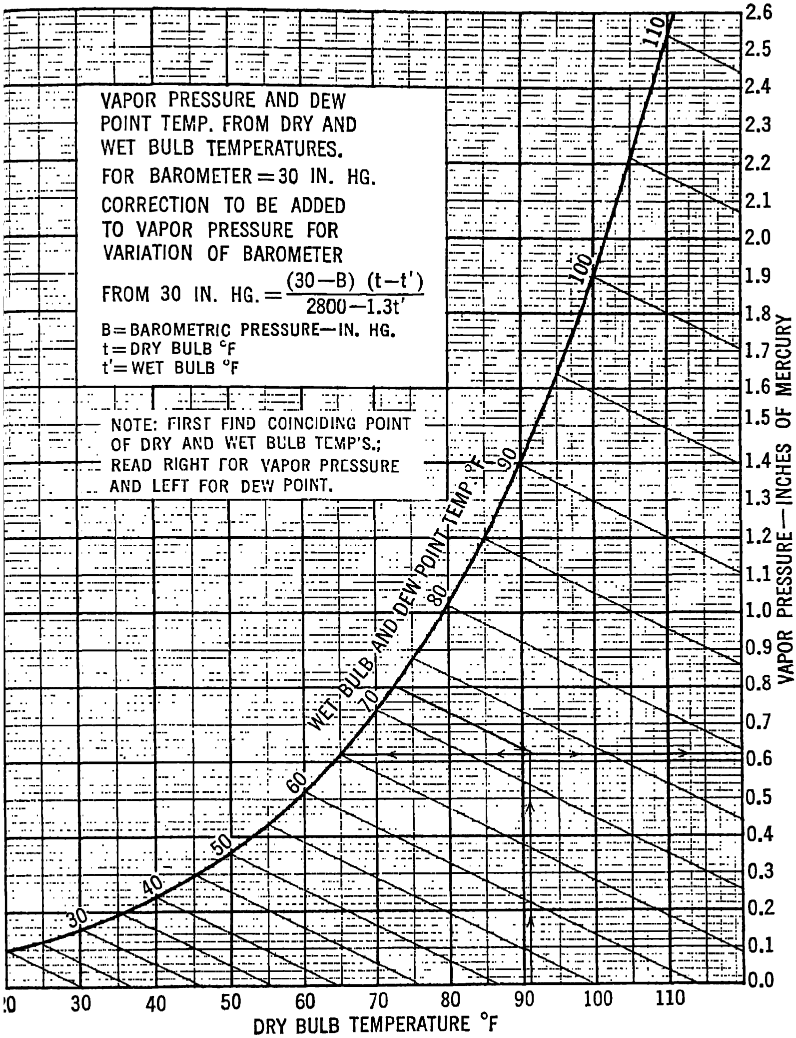
Courtesy Pratt and Whitney Aircraft

B. M. E. P. CHART



Courtesy Pratt and Whitney Aircraft

PSYCHROMETRIC CHART

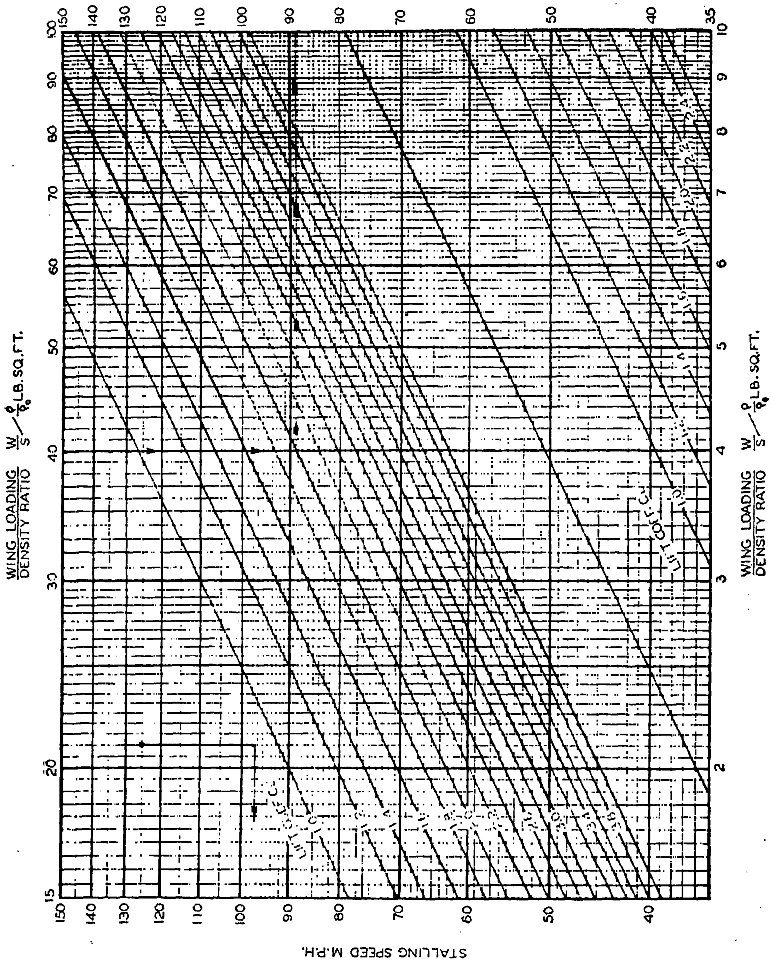


Courtesy Pratt and Whitney Aircraft

STALLING SPEED CHART

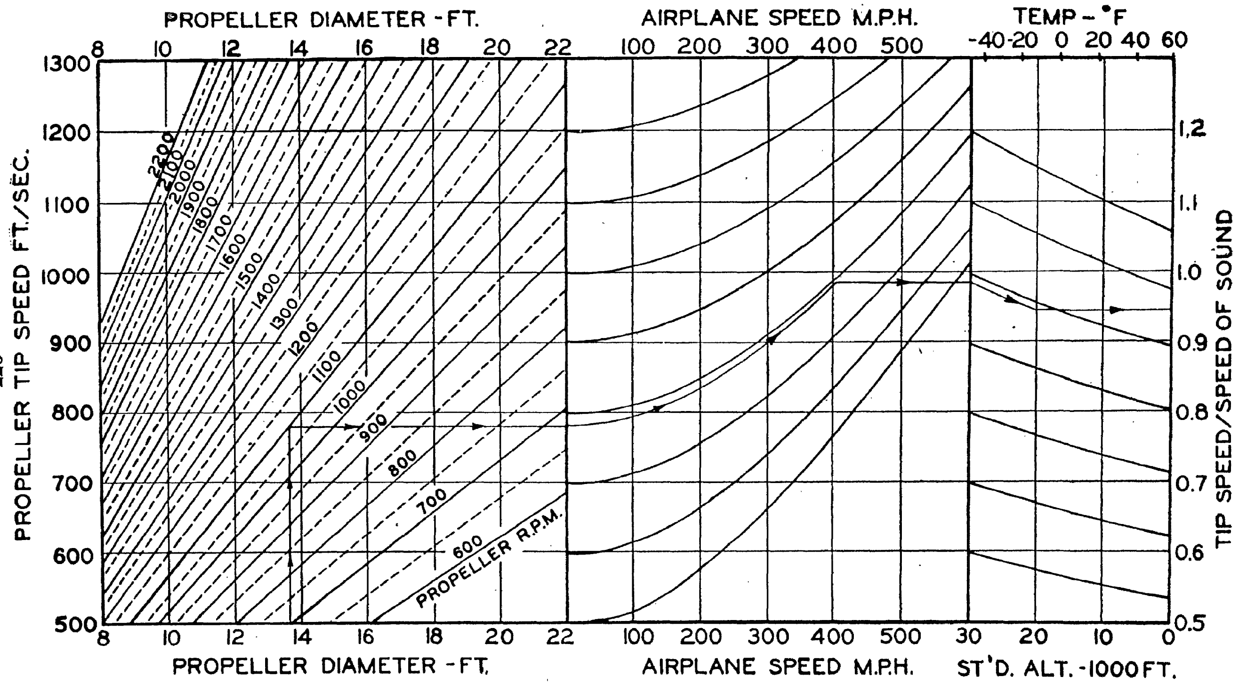
EXAMPLE

GIVEN: Wing loading = 40 lb sq ft. Density ratio = 1. Lift coefficient = 20.
OBTAIN: Stalling speed = 88.5 mph.



Courtesy Pratt and Whitney Aircraft

PROPELLER TIP SPEED CHART



Courtesy Pratt and Whitney Aircraft

EXAMPLE

GIVEN: Prop. diam. = 13.67 ft. Prop. speed = 1100 rpm. Airplane speed = 400 mph. Alt. = 20,000 ft.
OBTAIN: Propeller tip speed = 982 ft./sec. V_T/C = .942.

TWIST DRILL SIZES AND DECIMAL EQUIVALENTS

Drill	Equivalent
80	0.013000
79½	0.013500
79	0.014000
78½	0.014500
78	0.015000
1/64	0.015625
77	0.016000
76	0.018000
75	0.020000
74½	0.021000
74	0.022000
73½	0.022500
73	0.023000
72	0.024000
71½	0.025000
71	0.026000
70	0.027000
69½	0.028000
69	0.029000
68½	0.029250
68	0.030000
67	0.031000
1/32	0.031250
66	0.032000
65	0.033000
64	0.035000
63	0.036000
62	0.037000
61	0.038000
60½	0.039000
60	0.040000
59	0.041000
58	0.042000
57	0.043000
56	0.046500
3/64	0.046875
55	0.052000
54	0.055000
53	0.059500
1/16	0.062500
52	0.063500
51	0.067000
50	0.070000
49	0.073000
48	0.076000
5/64	0.078125
47	0.078500
46	0.081000
45	0.082000
44	0.086000
43	0.089000
42	0.093500
3/32	0.093750
41	0.096000
40	0.098000
39	0.099500
38	0.101500
37	0.104000
36	0.106500
7/64	0.109375
35	0.110000
34	0.111000
33	0.113000
32	0.116000
31	0.120000
1/8	0.125000
30	0.128500
29	0.136000
28	0.140500
9/64	0.140625
27	0.144000
26	0.147000
25	0.149500
24	0.152000
23	0.154000
5/32	0.156250
22	0.157000
21	0.159000
20	0.161000
19	0.166000
18	0.169500
11/64	0.171875
17	0.173000
16	0.177000
15	0.180000
14	0.182000
13	0.185000
3/16	0.187500
12	0.189000
11	0.191000
10	0.193500
9	0.196000
8	0.199000
7	0.201000
13/64	0.203125
6	0.204000
5	0.205500
4	0.209000
3	0.213000
7/32	0.218750
2	0.221000
1	0.228000
A	0.234000
15/64	0.234375
B	0.238000
C	0.242000
D	0.246000
E 1/4	0.250000
F	0.257000
G	0.261000
17/64	0.265625
H	0.266000
I	0.272000
J	0.277000
K	0.281000
9/32	0.281250
L	0.290000
M	0.295000
19/64	0.296875
N	0.302000
5/16	0.312500
O	0.316000
P	0.323000
21/64	0.328125
Q	0.332000
R	0.339000
11/32	0.343750
S	0.348000
T	0.358000
23/64	0.359375
U	0.368000
3/8	0.375000
V	0.377000
W	0.386000
25/64	0.390625
X	0.397000
Y	0.404000
13/32	0.406250
Z	0.413000
27/64	0.421875
7/16	0.437500
29/64	0.453125
15/32	0.468750
31/64	0.484375
1/2	0.500000
33/64	0.515625
17/32	0.531250
35/64	0.546875
9/16	0.562500
37/64	0.578125
19/32	0.593750
39/64	0.609375
5/8	0.625000
41/64	0.640625
21/32	0.656250
43/64	0.671875
11/16	0.687500
45/64	0.703125
23/32	0.718750
47/64	0.734375
3/4	0.750000
49/64	0.765625
25/32	0.781250
51/64	0.796875
13/16	0.812500
53/64	0.828125
27/32	0.843750
55/64	0.859375
7/8	0.875000
57/64	0.890625
29/32	0.906250
59/64	0.921875
15/16	0.937500
61/64	0.953125
31/32	0.968750
63/64	0.984375
1	1.000000

CIRCUMFERENCES AND AREAS OF CIRCLES WITH FRACTIONAL INCH DIAMETER

Diam.	Circumference	Area	Diam.	Circumference	Area	Diam.	Circumference	Area
1/32	0.0982	0.0008	2 3/16	6.8722	3.7583	7 5/8	23.9546	45.6634
1/16	0.1964	0.0031	2 1/4	7.0686	3.9761	7 3/4	24.3473	47.1729
3/32	0.2945	0.0069	2 5/16	7.2649	4.2000	7 7/8	24.7400	48.7069
1/8	0.3927	0.0123	2 3/8	7.4613	4.4301	8	25.1327	50.2654
5/32	0.4909	0.0192	2 7/16	7.6576	4.6664	8 1/4	25.9181	53.4561
3/16	0.5890	0.0276	2 1/2	7.8540	4.9087	8 1/2	26.7035	56.7419
7/32	0.6872	0.0376	2 9/16	8.0503	5.1572	8 3/4	27.4889	60.1320
1/4	0.7854	0.0491	2 5/8	8.2467	5.4119	9	28.2743	63.6172
9/32	0.8836	0.0621	2 11/16	8.4430	5.6727	9 1/4	29.0597	67.2006
5/16	0.9817	0.0767	2 3/4	8.6394	5.9396	9 1/2	29.8451	70.8821
11/32	1.0799	0.0928	2 13/16	8.8357	6.2126	9 3/4	30.6305	74.6618
3/8	1.1781	0.1105	2 7/8	9.0321	6.4918	10	31.4159	78.5398
13/32	1.2763	0.1296	2 15/16	9.2284	6.7771	10 1/4	32.2013	82.5158
7/16	1.3745	0.1503	3	9.4248	7.0686	10 1/2	32.9867	86.5901
15/32	1.4726	0.1726	3 1/8	9.8175	7.6699	10 3/4	33.7721	90.7625
1/2	1.5708	0.1964	3 1/4	10.2102	8.2958	11	34.5575	95.0331
17/32	1.6690	0.2217	3 3/8	10.6029	8.9462	11 1/4	35.3429	99.4019
9/16	1.7672	0.2485	3 1/2	10.9956	9.6211	11 1/2	36.1283	103.868
19/32	1.8653	0.2769	3 5/8	11.3883	10.3206	11 3/4	36.9137	108.434
5/8	1.9635	0.3068	3 3/4	11.7810	11.0447	12	37.6991	113.097
21/32	2.0617	0.3382	3 7/8	12.1737	11.7933	12 1/4	38.4845	117.859
11/16	2.1598	0.3712	4	12.5664	12.5664	12 1/2	39.2699	122.718
23/32	2.2580	0.4057	4 1/8	12.9591	13.3641	12 3/4	40.0553	127.677
3/4	2.3562	0.4418	4 1/4	13.3518	14.1863	13	40.8407	132.732
25/32	2.4544	0.4794	4 3/8	13.7445	15.0330	13 1/4	41.6261	137.886
13/16	2.5525	0.5185	4 1/2	14.1372	15.9044	13 1/2	42.4115	143.139
27/32	2.6507	0.5591	4 5/8	14.5299	16.8002	13 3/4	43.1969	148.489
7/8	2.7489	0.6013	4 3/4	14.9226	17.7206	14	43.9823	153.938
29/32	2.8471	0.6450	4 7/8	15.3153	18.6655	14 1/4	44.7677	159.485
15/16	2.9452	0.6903	5	15.7080	19.6350	14 1/2	45.5531	165.130
31/32	3.0434	0.7371	5 1/8	16.1007	20.6290	14 3/4	46.3385	170.873
1	3.1416	0.7854	5 1/4	16.4934	21.6476	15	47.1239	176.715
1 1/16	3.3379	0.8866	5 3/8	16.8861	22.6907	15 1/2	48.6947	188.695
1 1/8	3.5343	0.9940	5 1/2	17.2788	23.7583	16	50.2655	201.062
1 3/16	3.7306	1.1075	5 5/8	17.6715	24.8505	16 1/2	51.8363	213.825
1 1/4	3.9270	1.2272	5 3/4	18.0642	25.9673	17	53.4071	226.980
1 5/16	4.1233	1.3530	5 7/8	18.4569	27.1086	17 1/2	54.9779	240.528
1 3/8	4.3197	1.4849	6	18.8496	28.2744	18	56.5487	254.469
1 7/16	4.5160	1.6230	6 1/8	19.2423	29.4648	18 1/2	58.1195	268.803
1 1/2	4.7124	1.7671	6 1/4	19.6350	30.6797	19	59.6903	283.529
1 9/16	4.9087	1.9175	6 3/8	20.0277	31.9191	19 1/2	61.2611	298.648
1 5/8	5.1051	2.0739	6 1/2	20.4204	33.1832	20	62.8319	314.160
1 11/16	5.3014	2.2365	6 5/8	20.8131	34.4717	20 1/2	64.4026	330.063
1 3/4	5.4978	2.4053	6 3/4	21.2058	35.7848	21	65.9734	346.360
1 13/16	5.6941	2.5802	6 7/8	21.5984	37.1223	21 1/2	67.5442	363.050
1 7/8	5.8905	2.7612	7	21.9911	38.4844	22	69.1150	380.133
1 15/16	6.0868	2.9483	7 1/8	22.3838	39.8711	22 1/2	70.6858	397.608
2	6.2832	3.1416	7 1/4	22.7765	41.2824	23	72.2566	415.475
2 1/16	6.4795	3.3410	7 3/8	23.1692	42.7182	23 1/2	73.8274	433.736
2 1/8	6.6759	3.5466	7 1/2	23.5619	44.1786	24	75.3982	452.389

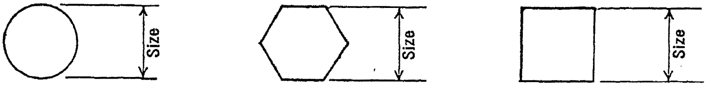
WIRE AND SHEET METAL GAUGES

(Diameters and thicknesses in decimal parts of an inch)

Gauge No.	American Wire Gauge or Brown & Sharpe (for copper wire)	Steel Wire Gauge, or Washburn & Moen or Roebling (for steel wire)	Birmingham Wire Gauge (B.W.G.) or Stubs' Iron Wire (for steel wire or sheets)	Stubs' Steel Wire Gauge	British Imperial Standard Wire Gauge (S.W.G.)	U. S. Standard Gauge for Sheet Metal (iron and steel)	Trenton Iron Co.	Standard Birmingham Sheet and hoop (B.G.)
0000000		0.4900			0.500	0.500		
000000		0.4615			0.464	0.469		
00000		0.4305			0.432	0.438	0.450	
0000	0.460	0.3938	0.454		0.400	0.406	0.400	
000	0.410	0.3625	0.425		0.372	0.375	0.360	0.5000
00	0.365	0.3310	0.380		0.348	0.344	0.330	0.4452
0	0.325	0.3065	0.340		0.324	0.312	0.305	0.3964
1	0.289	0.2830	0.300	0.227	0.300	0.281	0.285	0.3532
2	0.258	0.2625	0.284	0.219	0.276	0.266	0.265	0.3147
3	0.229	0.2437	0.259	0.212	0.252	0.250	0.245	0.2804
4	0.204	0.2253	0.238	0.207	0.232	0.234	0.225	0.2500
5	0.182	0.2070	0.220	0.204	0.212	0.219	0.205	0.2225
6	0.162	0.1920	0.203	0.201	0.192	0.203	0.190	0.1981
7	0.144	0.1770	0.180	0.199	0.176	0.188	0.175	0.1764
8	0.128	0.1620	0.165	0.197	0.160	0.172	0.160	0.1570
9	0.114	0.1483	0.148	0.194	0.144	0.156	0.145	0.1398
10	0.102	0.1350	0.134	0.191	0.128	0.141	0.130	0.1250
11	0.091	0.1205	0.120	0.188	0.116	0.125	0.1175	0.1113
12	0.081	0.1055	0.109	0.185	0.104	0.109	0.105	0.0991
13	0.072	0.0915	0.095	0.182	0.092	0.094	0.0925	0.0882
14	0.064	0.0800	0.083	0.180	0.080	0.078	0.080	0.0785
15	0.057	0.0720	0.072	0.178	0.072	0.070	0.070	0.0699
16	0.051	0.0625	0.065	0.175	0.064	0.062	0.061	0.0625
17	0.045	0.0540	0.058	0.172	0.056	0.056	0.0525	0.0556
18	0.040	0.0475	0.049	0.168	0.048	0.050	0.045	0.0495
19	0.036	0.0410	0.042	0.164	0.040	0.0438	0.040	0.0440
20	0.032	0.0348	0.035	0.161	0.036	0.0375	0.035	0.0392
21	0.0285	0.0317	0.032	0.157	0.032	0.0344	0.031	0.0349
22	0.0253	0.0286	0.028	0.155	0.028	0.0312	0.028	0.0313
23	0.0226	0.0258	0.025	0.153	0.024	0.0281	0.025	0.0278
24	0.0201	0.0230	0.022	0.151	0.022	0.0250	0.0225	0.0248
25	0.0179	0.0204	0.020	0.148	0.020	0.0219	0.020	0.0220
26	0.0159	0.0181	0.018	0.146	0.018	0.0188	0.018	0.0196
27	0.0142	0.0173	0.016	0.143	0.0164	0.0172	0.017	0.0175
28	0.0126	0.0162	0.014	0.139	0.0148	0.0156	0.016	0.0156
29	0.0113	0.0150	0.013	0.134	0.0136	0.0141	0.015	0.0139
30	0.0100	0.0140	0.012	0.127	0.0124	0.0125	0.014	0.0123
31	0.0089	0.0132	0.010	0.120	0.0116	0.0109	0.013	0.0110
32	0.0080	0.0128	0.009	0.115	0.0108	0.0102	0.012	0.0098
33	0.0071	0.0118	0.008	0.112	0.0100	0.0094	0.011	0.0087
34	0.0063	0.0104	0.007	0.110	0.0092	0.0086	0.010	0.0077
35	0.0056	0.0095	0.005	0.108	0.0084	0.0078	0.0095	0.0069
36	0.0050	0.0090	0.004	0.106	0.0076	0.0070	0.009	0.0061
37	0.0045	0.0085		0.103	0.0068	0.0066	0.0085	0.0054
38	0.0040	0.0080		0.101	0.0060	0.0062	0.008	0.0048
39	0.0035	0.0075		0.099	0.0052		0.0075	
40	0.0031	0.0070		0.097	0.0048		0.007	
41		0.0066		0.095	0.0044			
42		0.0062		0.092	0.0040			
43		0.0060		0.088	0.0036			
44		0.0058		0.085	0.0032			
45		0.0055		0.081	0.0028			
46		0.0052		0.079	0.0024			
47		0.0050		0.077	0.0020			
48		0.0048		0.075	0.0016			
49		0.0046		0.072	0.0012			
50		0.0044		0.069	0.0010			

To avoid confusion, because of the numerous gauge standards, the gauge number should always be followed by the decimal equivalent in inches in parenthesis. Example: AWG No. 00 (0.365) copper wire.

WEIGHT PER FOOT OF STEEL BARS (LB)



Size	Round	Hex	Square	Size	Round	Hex	Square
1/32	0.003	0.0033	0.0033	1 25/32	8.473	9.343	10.788
1/16	0.010	0.0115	0.014	1 13/16	8.733	9.673	11.170
3/32	0.023	0.026	0.031	1 27/32	9.078	10.009	11.558
1/8	0.042	0.046	0.053	1 7/8	9.388	10.352	11.953
5/32	0.065	0.072	0.083	1 29/32	9.704	10.699	12.355
3/16	0.094	0.104	0.119	1 15/16	10.024	11.053	12.763
7/32	0.128	0.141	0.163	1 31/32	10.350	11.413	13.178
1/4	0.167	0.184	0.212	2	10.681	11.778	13.600
9/32	0.211	0.233	0.269	2 1/32	11.018	......	14.028
5/16	0.261	0.288	0.332	2 1/16	11.360	12.525	14.463
11/32	0.316	0.348	0.402	2 3/32	11.706	......	14.905
3/8	0.376	0.414	0.478	2 1/8	12.058	13.296	15.353
13/32	0.441	0.486	0.561	2 5/32	12.416	......	15.808
7/16	0.511	0.564	0.651	2 3/16	12.778	14.089	16.270
15/32	0.587	0.647	0.747	2 7/32	13.146	......	16.738
1/2	0.668	0.736	0.850	2 1/4	13.519	14.907	17.213
17/32	0.754	0.831	0.960	2 9/32	13.897	......	17.694
9/16	0.845	0.932	1.076	2 5/16	14.280	15.746	18.182
19/32	0.941	1.038	1.199	2 11/32	14.669	......	18.677
5/8	1.043	1.150	1.328	2 3/8	15.063	16.609	19.178
21/32	1.150	1.268	1.464	2 13/32	15.462	......	19.686
11/16	1.262	1.392	1.607	2 7/16	15.866	17.494	20.201
23/32	1.379	1.521	1.756	2 15/32	16.275	......	20.722
3/4	1.502	1.656	1.913	2 1/2	16.690	18.403	21.250
25/32	1.630	1.797	2.075	2 17/32	17.110	......	21.785
13/16	1.763	1.944	2.245	2 9/16	17.535	19.335	22.326
27/32	1.901	2.096	2.421	2 19/32	17.965	......	22.874
7/8	2.044	2.254	2.603	2 5/8	18.400	20.289	23.428
29/32	2.193	2.418	2.792	2 21/32	18.841	......	23.989
15/16	2.347	2.588	2.988	2 11/16	19.287	21.267	24.557
31/32	2.506	2.763	3.191	2 23/32	19.738	......	25.131
1	2.670	2.945	3.400	2 3/4	20.195	22.268	25.713
1 1/32	2.840	3.131	3.616	2 25/32	20.656	......	26.300
1 1/16	3.014	3.324	3.838	2 13/16	21.123	23.291	26.895
1 3/32	3.194	3.523	4.067	2 27/32	21.595	......	27.496
1 1/8	3.379	3.727	4.303	2 7/8	22.072	24.338	28.103
1 5/32	3.570	3.937	4.546	2 29/32	22.555	......	28.717
1 3/16	3.766	4.152	4.795	2 15/16	23.042	25.408	29.338
1 7/32	3.966	4.374	5.050	2 31/32	23.535	......	29.966
1 1/4	4.173	4.601	5.313	3	24.033	26.500	30.600
1 9/32	4.384	4.834	5.581	3 1/16	25.045	27.616	31.888
1 5/16	4.600	5.072	5.857	3 1/8	26.078	28.755	33.203
1 11/32	4.822	5.317	6.139	3 3/16	27.131	29.916	34.545
1 3/8	5.049	5.567	6.428	3 1/4	28.206	31.101	35.913
1 13/32	5.281	5.823	6.724	3 5/16	29.301	32.309	37.307
1 7/16	5.518	6.085	7.026	3 3/8	30.417	33.540	38.728
1 15/32	5.761	6.352	7.335	3 7/16	31.554	34.793	40.176
1 1/2	6.008	6.625	7.650	3 1/2	32.712	36.070	41.650
1 17/32	6.261	6.904	7.972	3 9/16	33.891	37.370	43.151
1 9/16	6.520	7.189	8.301	3 5/8	35.090	38.692	44.678
1 19/32	6.783	7.479	8.636	3 11/16	36.311	40.038	46.232
1 5/8	7.051	7.775	8.978	3 3/4	37.552	41.407	47.813
1 21/32	7.325	8.077	9.327	3 13/16	38.814	42.799	49.420
1 11/16	7.604	8.385	9.682	3 7/8	40.097	44.213	51.053
1 23/32	7.889	8.699	10.044	3 15/16	41.401	45.651	52.713
1 3/4	8.178	9.018	10.413	4	42.726	47.112	54.400

To use above weights for other metals use percentage shown below.

Steel equals......... 100.0%
2S Aluminum equals.. 34.5%
17S Aluminum alloy equals............ 35.6%
Lead equals......... 145.0%
Commercial brass equals............ 108.5%
Commercial bronze equals............ 104.0%
Tobin bronze equals.. 107.0%
Copper equals....... 113.5%
Monel Metal equals... 113.5%
Rubber equals....... 14.3%
Hard fiber equals.... 16.4%
Zinc equals......... 90.0%

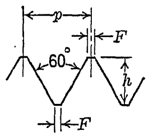
HARDNESS CONVERSION TABLE

Shore Universal Sclerescope	Rockwell B-1/16 Ball	C Diam'd	Brinell 10 mm* 3000 kg	Tensile Strength lb/sq in.	Shore Universal Sclerescope	Rockwell B-1/16 Ball	C Diam'd	Brinell 10 mm* 3000 kg	Tensile Strength lb./sq in.
			18	10,000	30	93	13	201	98,500
			20	12,000	31	94	14	206	100,500
			24	14,000	32	95	15	210	102,400
			28	16,000	32	95	16	215	104,600
			32	18,000	33	96	17	220	106,800
			35	20,000	33	97	18	225	109,000
			39	22,000	34	97	19	230	110,000
			42	24,000	35	98	20	235	113,200
			46	26,000	36	99	21	241	115,800
			50	28,000	36	100	22	247	118,500
	3		53	30,000	37	101	23	253	121,200
	10		57	32,000	38	102	24	259	124,000
	15		60	34,000	39	102	25	265	126,500
	22		64	36,000	40	103	26	272	129,500
	28		68	38,000	41	104	27	279	133,000
	33		72	40,000	42	105	28	286	135,000
	38		76	42,000	43	106	29	294	139,500
	43		79	44,000	44	106	30	301	142,300
	47		83	46,000	45	107	31	309	146,000
	50		87	48,000	46	108	32	318	150,000
	54		92	50,000	47	109	33	327	153,800
	57		96	52,000	48	110	34	337	158,000
	60		100	54,000	50	111	35	347	162,800
	62		104	56,000	51	111	36	357	167,800
	65		108	58,000	52	113	37	367	173,500
	67		113	60,000	53	114	38	377	179,600
	69		117	62,000	54	115	39	387	186,000
	71		122	64,000	56	116	40	398	193,000
	73		127	66,000	57	117	41	408	200,000
	75		131	68,000	58		42	419	206,500
	76		136	70,000	59		43	430	213,400
	78		140	72,000	61		44	442	221,000
	80		145	74,000	62		45	453	231,600
	81		150	76,000	63		46	464	236,600
	82		154	78,000	65		47	476	245,500
25	84		158	80,000	66		48	488	255,500
25	85	1	160	80,700	67		49	500	263,500
25	85	2	162	81,500	69		50	512	273,000
26	86	3	165	82,800	70		51	524	283,000
26	87	4	168	84,000	71		52	536	
26	88	4	171	85,000	73		53	548	
27	88	5	174	87,000	74		56		
28	88	6	177	88,000	76		57		
29	89	7	180	89,200	77		58		
29	89	8	183	90,600	78		59		
29	90	9	186	91,800	80		60		
29	91	10	190	93,800	81		61		
30	91	11	193	95,000	82		62		
30	92	12	197	95,800	84		63		

* Tungsten carbide ball.

The relationship between the tensile strength and hardness is indicated. This table is to be used as a guide. It applies only to the plain carbon and low alloy steels and not to corrosion-resistant, magnet, or valve steels or nonferrous metals. When a narrow range of hardness is required the tests for determining the relationship between hardness and strength should be made on the actual part.

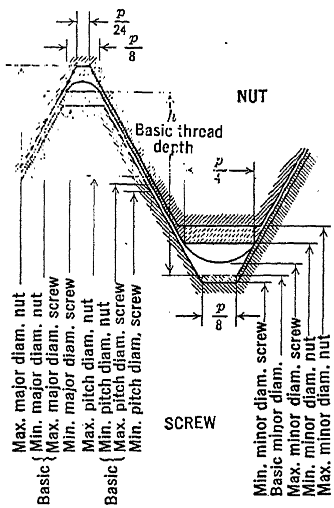
AMERICAN NATIONAL THREAD FORM



p = Pitch of thread $= \dfrac{1}{\text{threads per inch}}$

h = Basic thread depth $= \dfrac{0.64952}{\text{threads per inch}} = 0.64952 \times p$

F = Width of flat of basic form $= \dfrac{1}{8 \text{ threads per inch}} =$ $0.1250 \times p$



The American National form of thread as shown above is similar to the S.A.E. and U. S. Standard forms. The American National coarse (NC) series is comparable to the S.A.E. coarse series and the U. S. Standard series. The American National Fine (NF) series is comparable to the S.A.E. Regular series.

The class 3 fit (written NF–3 or NC–3) is intended for aircraft and engine work in general, where the minimum amount of shake or play between threaded parts is desirable.

When externally threaded parts are to be plated, the pitch diameter tolerance may be increased on the negative side by not more than 0.001 in. on all threads for which the pitch diameter tolerance specified does not exceed 0.0035 in. The plated thread, however, must conform to the tolerance requirements.

Coarse Thread Series, Class 3 Fit Symbol NC-3

Size	Threads per Inch	Pitch Diameter			Screw Diameters			Nut Diameters		
		Basic	Tolerance		Major		Minor	Major	Minor*	
			Screw	Nut	Max.	Toler.	Max.	Min.	Min.	Toler.
1	64	0.0629	+0.0000 −0.0014	+0.0014 −0.0000	0.0730	+0.0000 −0.0038	0.0538	0.0730	0.0561	+0.0062 −0.0000
2	56	0.0744	+0.0000 −0.0015	+0.0015 −0.0000	0.0860	+0.0000 −0.0040	0.0641	0.0860	0.0667	+0.0070 −0.0000
3	48	0.0855	+0.0000 −0.0016	+0.0016 −0.0000	0.0990	+0.0000 −0.0044	0.0734	0.0990	0.0764	+0.0077 −0.0000
4	40	0.0958	+0.0000 −0.0017	+0.0017 −0.0000	0.1120	+0.0000 −0.0048	0.0813	0.1120	0.0849	+0.0089 −0.0000
5	40	0.1088	+0.0000 −0.0017	+0.0017 −0.0000	0.1250	+0.0000 −0.0048	0.0943	0.1250	0.0979	+0.0083 −0.0000
6	32	0.1177	+0.0000 −0.0019	+0.0019 −0.0000	0.1380	+0.0000 −0.0054	0.0997	0.1380	0.1042	+0.0103 −0.0000
8	32	0.1437	+0.0000 −0.0019	+0.0019 −0.0000	0.1640	+0.0000 −0.0054	0.1257	0.1640	0.1302	+0.0082 −0.0000
10	24	0.1629	+0.0000 −0.0024	+0.0024 −0.0000	0.1900	+0.0000 −0.0066	0.1389	0.1900	0.1449	+0.0110 −0.0000
¼	20	0.2175	+0.0000 −0.0026	+0.0026 −0.0000	0.2500	+0.0000 −0.0072	0.1887	0.2500	0.1959	+0.0101 −0.0000
5/16	18	0.2764	+0.0000 −0.0030	+0.0030 −0.0000	0.3125	+0.0000 −0.0082	0.2443	0.3125	0.2524	+0.0106 −0.0000
⅜	16	0.3344	+0.0000 −0.0032	+0.0032 −0.0000	0.3750	+0.0000 −0.0090	0.2983	0.3750	0.3073	+0.0111 −0.0000
7/16	14	0.3911	+0.0000 −0.0036	+0.0036 −0.0000	0.4375	+0.0000 −0.0098	0.3499	0.4375	0.3602	+0.0119 −0.0000
½	13	0.4500	+0.0000 −0.0037	+0.0037 −0.0000	0.5000	+0.0000 −0.0104	0.4056	0.5000	0.4167	+0.0123 −0.0000
9/16	12	0.5084	+0.0000 −0.0040	+0.0040 −0.0000	0.5625	+0.0000 −0.0112	0.4603	0.5625	0.4723	+0.0127 −0.0000
⅝	11	0.5660	+0.0000 −0.0042	+0.0042 −0.0000	0.6250	+0.0000 −0.0118	0.5135	0.6250	0.5266	+0.0131 −0.0000
¾	10	0.6850	+0.0000 −0.0045	+0.0045 −0.0000	0.7500	+0.0000 −0.0128	0.6273	0.7500	0.6417	+0.0136 −0.0000
⅞	9	0.8028	+0.0000 −0.0049	+0.0049 −0.0000	0.8750	+0.0000 −0.0140	0.7387	0.8750	0.7547	+0.0142 −0.0000
1	8	0.9188	+0.0000 −0.0054	+0.0054 −0 0000	1.0000	+0.0000 −0.0152	0.8466	1.0000	0.8647	+0.0148 −0.0000

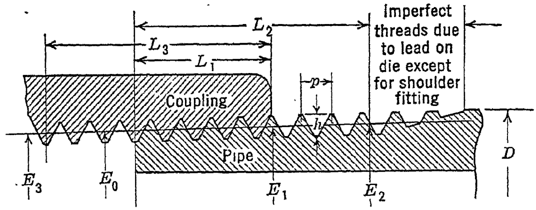
For larger sizes use 8-thread series.
* The minor diameter for internal threads is the hole diameter before threading.

Fine Thread Series, Class 3 Fit Symbol NF-3

Size	Threads per Inch	Pitch Diameter Basic	Pitch Diameter Tolerance Screw	Pitch Diameter Tolerance Nut	Screw Diameters Major Max.	Screw Diameters Major Toler.	Screw Diameters Minor Max.	Nut Diameters Major Min.	Nut Diameters Minor* Min.	Nut Diameters Minor* Toler.
0	80	0.0519	+0.0000 −0.0013	+0.0013 −0.0000	0.0600	+0.0000 −0.0034	0.0447	0.0600	0.0465	+0.0049 −0.0000
1	72	0.0640	+0.0000 −0.0013	+0.0013 −0.0000	0.0730	+0.0000 −0.0036	0.0560	0.0730	0.0580	+0.0054 −0.0000
2	64	0.0759	+0.0000 −0.0014	+0.0014 −0.0000	0.0860	+0.0000 −0.0038	0.0668	0.0860	0.0691	+0.0055 −0.0000
3	56	0.0874	+0.0000 −0.0015	+0.0015 −0.0000	0.0990	+0.0000 −0.0040	0.0771	0.0990	0.0797	+0.0059 −0.0000
4	48	0.0985	+0.0000 −0.0016	+0.0016 −0.0000	0.1120	+0.0000 −0.0044	0.0864	0.1120	0.0894	+0.0063 −0.0000
5	44	0.1102	+0.0000 −0.0016	+0.0016 −0.0000	0.1250	+0.0000 −0.0046	0.0971	0.1250	0.1004	+0.0064 −0.0000
6	40	0.1218	+0.0000 −0.0017	+0.0017 −0.0000	0.1380	+0.0000 −0.0048	0.1073	0.1380	0.1109	+0.0070 −0.0000
8	36	0.1460	+0.0000 −0.0018	+0.0018 −0.0000	0.1640	+0.0000 −0.0050	0.1299	0.1640	0.1339	+0.0063 −0.0000
10	32	0.1697	+0.0000 −0.0019	+0.0019 −0.0000	0.1900	+0.0000 −0.0054	0.1517	0.1900	0.1562	+0.0062 −0.0000
1/4	28	0.2268	+0.0000 −0.0022	+0.0022 −0.0000	0.2500	+0.0000 −0.0062	0.2062	0.2500	0.2113	+0.0060 −0.0060
5/16	24	0.2854	+0.0000 −0.0024	+0.0024 −0.0000	0.3125	+0.0000 −0.0066	0.2614	0.3125	0.2674	+0.0065 −0.0000
3/8	24	0.3479	+0.0000 −0.0024	+0.0024 −0.0000	0.3750	+0.0000 −0.0066	0.3239	0.3750	0.3299	+0.0065 −0.0000
7/16	20	0.4050	+0.0000 −0.0026	+0.0026 −0.0000	0.4375	+0.0000 −0.0072	0.3762	0.4375	0.3834	+0.0072 −0.0000
1/2	20	0.4675	+0.0000 −0.0026	+0.0026 −0.0000	0.5000	+0.0000 −0.0072	0.4387	0.5000	0.4459	+0.0072 −0.0000
9/16	18	0.5264	+0.0000 −0.0030	+0.0030 −0.0000	0.5625	+0.0000 −0.0082	0.4943	0.5625	0.5024	+0.0076 −0.0000
5/8	18	0.5889	+0.0000 −0.0030	+0.0030 −0.0000	0.6250	+0.0000 −0.0082	0.5568	0.6250	0.5649	+0.0076 −0.0000
3/4	16	0.7094	+0.0000 −0.0032	+0.0032 −0.0000	0.7500	+0.0000 −0.0090	0.6733	0.7500	0.6823	+0.0080 −0.0000
7/8	14	0.8286	+0.0000 −0.0036	+0.0036 −0.0000	0.8750	+0.0000 −0.0098	0.7874	0.8750	0.7977	+0.0085 −0.0000
1	14	0.9536	+0.0000 −0.0036	+0.0036 −0.0000	1.0000	+0.0000 −0.0098	0.9124	1.0000	0.9227	+0.0085 −0.0000
1 1/8	12	1.0709	+0.0000 −0.0040	+0.0040 −0.0000	1.1250	+0.0000 −0.0112	1.0228	1.1250	1.0348	+0.0090 −0.0000
1 1/4	12	1.1959	+0.0000 −0.0040	+0.0040 −0.0000	1.2500	+0.0000 −0.0112	1.1478	1.2500	1.1598	+0.0090 −0.0000
1 3/8	12	1.3209	+0.0000 −0.0040	+0.0040 −0.0000	1.3750	+0.0000 −0.0112	1.2728	1.3750	1.2848	+0.0090 −0.0000
1 1/2	12	1.4459	+0.0000 −0.0040	+0.0040 −0.0000	1.5000	+0.0000 −0.0112	1.3978	1.5000	1.4098	+0.0090 −0.0000

For larger sizes use 12-thread series.
* The minor diameter for internal threads is the hole diameter before threading.

DIMENSIONS OF AMERICAN NATIONAL TAPER PIPE THREADS



D = Outside diameter of pipe = Major diameter of pipe thread at L_2 from end of pipe.
L_1 = Normal engagement by hand between external and internal thread
L_2 = Effective length of external thread = $p(0.8D + 6.8)$.
L_3 = Effective length of internal thread = $L_1 + 3p$.
E_0 = Basic pitch diameter of thread at end of pipe = $D - (0.05D + 1.1)p$.
E_1 = Basic pitch diameter of thread at end of coupling = $E_0 + 0.0625L_1$.
E_2 = Basic pitch diameter of thread at L_2 from end of pipe = $E_0 + 0.0625L_2$.
E_3 = Basic pitch diameter of thread at L_3 from end of coupling = $E_0 - 0.1875p$.

AMERICAN NATIONAL TAPER PIPE THREADS — SYMBOL NPT

Nominal Pipe Size	Thr'ds per Inch (n)	Pitch $= 1/n$ (p')	Depth of Thr'd h(max)	D	Basic Lengths			Basic Pitch Diameters				Tap Drill Size
					L_1	L_2	L_3	E_0	E_1	E_2	E_3	
Inches		Inch	Inch	Inches	Inch	Inches	Inches	Inches	Inches	Inches	Inches	
1	2	3	4	5	6	7	8	9	10	11	12	13
1/8	27	0.03704	0.02963	0.405	0.180	0.2639	0.2911	0.36351	0.37476	0.38000	0.35657	21/64
1/4	18	0.05556	0.04444	0.540	0.200	0.4018	0.3667	0.47739	0.48989	0.50250	0.46696	27/64
3/8	18	0.05556	0.04444	0.675	0.240	0.4078	0.4067	0.61201	0.62701	0.63750	0.60158	9/16
1/2	14	0.07143	0.05714	0.840	0.320	0.5337	0.5343	0.75843	0.77843	0.79179	0.74504	11/16
3/4	14	0.07143	0.05714	1.050	0.339	0.5457	0.5533	0.96768	0.98887	1.00179	0.95429	29/32
1	11 1/2	0.08696	0.06957	1.315	0.400	0.6828	0.6609	1.21363	1.23863	1.25630	1.19732	1 1/8
1 1/4	11 1/2	0.08696	0.06957	1.660	0.420	0.7068	0.6809	1.55713	1.58338	1.60130	1.54082	1 15/32
1 1/2	11 1/2	0.08696	0.06957	1.900	0.420	0.7235	0.6809	1.79609	1.82234	1.84130	1.77978	1 23/32
2	11 1/2	0.08696	0.06957	2.375	0.436	0.7565	0.6969	2.26902	2.29627	2.31630	2.25271	2 3/16
2 1/2	8	0.12500	0.10000	2.875	0.682	1.1375	1.0570	2.71953	2.76216	2.79062	2.69609	2 9/16
3	8	0.12500	0.10000	3.500	0.766	1.2000	1.1410	3.34062	3.38850	3.41562	3.31718	3 3/16

WEIGHTS AND MEASURES

Measures of Length

1 mile = 1760 yards = 5280 feet.
1 yard = 3 feet = 36 inches. 1 foot = 12 inches.
The following measures of length are also used occasionally:
1 mil = 0.001 inch. 1 fathom = 2 yards = 6 feet.
1 rod = 5.5 yards = 16.5 feet. 1 hand = 4 inches. 1 span = 9 inches.

Surveyor's Measure

1 mile = 8 furlongs = 80 chains. 1 furlong = 10 chains = 220 yards.
1 chain = 4 rods = 22 yards = 66 feet = 100 links. 1 link = 7.92 inches.

Nautical Measure

1 league = 3 nautical miles.
1 nautical mile (knot) = 6080.26 feet = 1.1516 statute miles.
One degree at the equator = 60 nautical miles = 69.168 statute miles.
360 degrees = 21,600 nautical miles = 24,874.5 statute miles = circumference of earth at the equator.

Square Measure

1 square mile = 640 acres = 6400 square chains.
1 acre = 10 square chains = 4840 square yards = 43,560 square feet.
1 square chain = 16 square rods = 484 square yards = 4356 square feet.
1 square rod = 30.25 square yards = 272.25 square feet = 625 square links.
1 square yard = 9 square feet. 1 square foot = 144 square inches.
An acre is equal to a square, the side of which is 208.7 feet.

Measure Used for Diameters and Areas of Electric Wires

1 circular inch = area of circle 1 inch in diameter = 0.7854 square inch.
1 circular inch = 1,000,000 circular mils.
1 square inch = 1.2732 circular inches = 1,273,239 circular mils.
A circular mil is the area of a circle 0.001 inch in diameter.

Cubic Measure

1 cubic yard = 27 cubic feet. 1 cubic foot = 1728 cubic inches.
The following measures are also used for wood and masonry:
1 cord of wood = 128 cubic feet.
1 perch of masonry = $24\frac{3}{4}$ cubic feet.

Shipping Measure

For measuring entire internal capacity of a vessel:
1 register ton = 100 cubic feet.
For measurement of cargo:
1 U. S. shipping ton = 40 cubic feet = 32.143 U. S. bushels = 31.16 Imperial bushels.
1 British shipping ton = 42 cubic feet = 33.73 U. S. bushels = 32.72 Imperial bushels.

Dry Measure

1 bushel (U. S. or Winchester struck bushel) = 1.2445 cubic foot = 2150.42 cubic inches.
1 bushel = 4 pecks = 32 quarts = 64 pints.
1 peck = 8 quarts = 16 pints. 1 quart = 2 pints.
1 heaped bushel = $1\frac{1}{4}$ struck bushels. 1 cubic foot = 0.8036 struck bushel.
1 British Imperial bushel = 8 Imperial gallons = 1.2837 cubic feet = 2218.19 cubic inches.

Liquid Measure

1 U. S. gallon = 0.1337 cubic foot = 231 cubic inches = 4 quarts = 8 pints.
1 quart = 2 pints = 8 gills.
1 pint = 4 gills.
1 British Imperial gallon = 1.2003 U. S. gallons = 277.27 cubic inches.
1 cubic foot = 7.48 U. S. gallons.

Apothecaries' Fluid Measure

1 U. S. fluid ounce = 8 drachms = 1.805 cubic inches = 1/128 U. S. gallon.
1 fluid drachm = 60 minims.
1 British fluid ounce = 1.732 cubic inches.

Avoirdupois or Commercial Weight

1 gross or long ton = 2240 pounds.
1 net or short ton = 2000 pounds.
1 pound = 16 ounces = 7,000 grains.
1 ounce = 16 drachms = 437.5 grains.
The following measures for weight are now seldom used in the United States:
1 hundred weight = 4 quarters = 112 pounds (1 gross or long ton = 20 hundredweights); 1 quarter = 28 pounds; 1 stone = 14 pounds; 1 quintal = 100 pounds.

Troy Weight

(Used for weighing gold and silver)

1 pound = 12 ounces = 5760 grains.
1 ounce = 20 pennyweights = 480 grains.
1 pennyweight = 24 grains.
1 carat (used in weighing diamonds) = 3.086 grains.
1 grain troy = 1 grain avoirdupois = 1 grain apothecaries' weight.

Apothecaries' Weight

1 pound = 12 ounces = 5,760 grains.
1 ounce = 8 drachms = 480 grains.
1 drachm = 3 scruples = 60 grains.
1 scruple = 20 grains.

Miscellaneous

1 great gross = 12 gross = 144 dozens.
1 gross = 12 dozens = 144 units.
1 dozen = 12 units
1 score = 20 units.
1 quire = 24 sheets.
1 ream = 20 quires = 480 sheets.
1 ream printing paper = 500 sheets.

A gallon of water (U. S. standard) weighs 8½ pounds and contains 231 cubic inches.
A cubic foot of water contains 7½ gallons, 1728 cubic inches, and weighs 62½ pounds at a temperature of about 39°F. The weight changes slightly above and below this temperature.
To find the pressure in pounds per square inch of a column of water, multiply the height of the column in feet by 0.434.
Steam rising from water at its boiling point (212°F) has a pressure equal to that of the atmosphere at sea level (14.7 pounds per square inch).

International Standards

	English	Metric
Gravity	32.1740 ft/sec^2	9.80665 m/sec^2
Air gas constant (R)	53.33	29.27
Absolute zero	−459.4°F	−273°C
Horsepower	550 ft-lb/sec	76.04 kg-m/sec
π	3.14159	3.14159

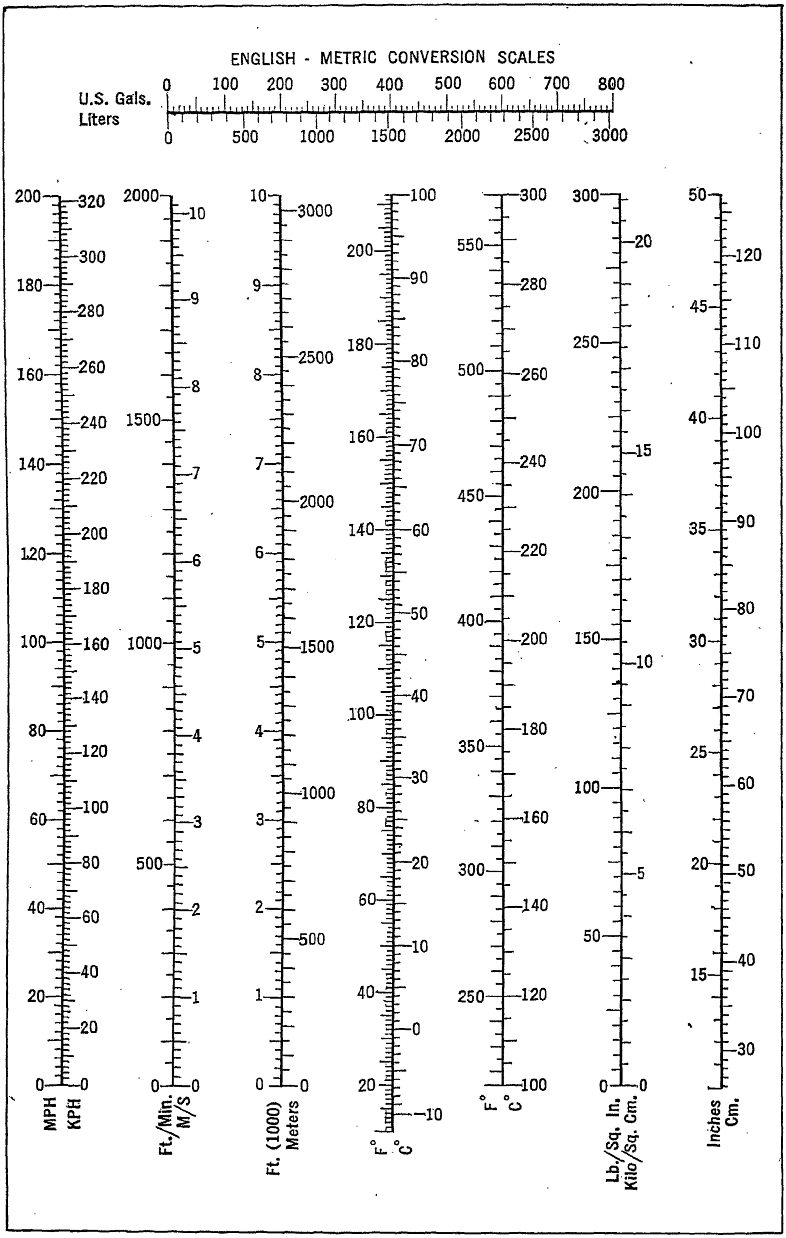
Standard Atmosphere

Standard Values at Sea Level

Pressure (P_o)	29.92 in. Hg	760 mm Hg
Pressure (P_o)	2116 lb/ft^2	10332 kg/m^2
Temperature (t_o)	59°F	15°C
Absolute temp. (T_o)	518.4°F $_{abs}$ °R, °Rankine	288°°C$_{abs}$°K, Kelvin
Specific weight ($g\rho_o$)	0.07651 lb/ft^3	0.12255 kg/m^3
Density (ρ_o)	0.002378 lb sec^2/ft^4	0.124966 kg sec^2/m^4

Standard Values at Altitude

Isothermal level (Z_i)	35332 ft	10769 m
Isothermal temp. (t_i)	−67°F	−55°C
Temp. gradient (a)	.003566°F/ft	.0065°C/m


ENGLISH - METRIC CONVERSION SCALES
U.S. Gals.
Liters
MPH
KPH
Ft./Min.
M/S
Ft. (1000)
Meters
F°
C°
F°
C°
Lb./Sq. In.
Kilo/Sq. Cm.
Inches
Cm.

CONVERSION FACTORS

Multiply	By	To Obtain
atmospheres	76	centimeters of mercury
"	29.9212	inches of mercury
"	33.8985	feet of water
"	10,332.276	kilograms per square meter
"	14.69601	pounds per square inch
"	2116.225	pounds per square foot
"	1.0133	bars
centimeters (cm)	0.393700	inches
"	0.0328083	feet
centimeters of mercury	5,352391	inches of water
"	0.4460326	feet of water
"	0.193368	pounds per square inch
"	27.84507	pounds per square foot
"	135.9510	kilograms per square meter
centimeters per second	0.0328083	feet per second
cubic centimeters	0.00099973	liters
" "	0.06102338	cubic inches
cubic feet	1728	cubic inches
" "	1/27	cubic yards
" "	7.480519	gallons
" "	28,317.017	cubic centimeters
" "	28.31625	liters
" "	0.028317017	cubic meters
cubic feet per minute	0.471704	liters per second
" " " "	0.028317	cubic meters per minute
cubic feet of water	62.42833	pounds
cubic inches	16.3871624	cubic centimeters
" "	0.0163876	liters
" "	1/231	gallons
cubic meters	61,023.3753	cubic inches
" "	35.3144548	cubic feet
" "	264.170	gallons
degrees (arc)	0.017453292	radians
feet	30.4800613	centimeters
"	0.3048006	meters
feet of water	0.029500	atmospheres
"	0.433530	pounds per square inch
"	62.428327	pounds per square foot
"	304.8006	kilograms per square meter
"	0.882671	inches of mercury
"	0.24199	centimeters of mercury
feet per minute	0.0113636	miles per hour
"	0.018288	kilometers per hour
"	0.508001	centimeters per second
feet per second	0.681818	miles per hour
"	1.09728220	kilometers per hour
"	30.48006	centimeters per second
"	0.3048006	meters per second
"	0.5920858	knots
foot-pounds	0.138255	meter-kilograms
foot-pounds per minute	1/33,000	horsepower
foot-pounds per second	1/550	horsepower
gallons	231	cubic inches
"	0.133680	cubic feet
"	3.785332	liters
"	0.832680	Imperial gallons
grams	15.43236	grains
"	0.0352739	ounces

CONVERSION FACTORS

Multiply	By	To Obtain
grams	0.0022046223	pounds
"	1000	milligrams
"	0.001	kilograms
"	980.665	dynes
gram-calories	0.0039685	Btu
grams per centimeter	0.1	kilograms per meter
"	0.06719702	pounds per foot
"	0.0055914	pounds per inch
grams per cubic centimeter	1000	kilograms per centimeter
"	62.42833	pounds per cubic foot
horsepower	33,000	foot-pounds per minute
"	550	foot-pounds per second
"	76.04039	kilogram-meters per second
"	1.013872	metric horsepower
horsepower, metric	75	kilogram-meters per second
"	0.986318	horsepower
horsepower-hours	2545.06	Btu
"	1,980,000	foot-pounds
"	273,745.4	kilogram-meters
inches	2.54000508	centimeters
inches of mercury	0.0334211	atmospheres
"	13.5951	inches of water
"	1.132925	feet of water
"	0.4911570	pounds per square inch
"	70.72661	pounds per square foot
inches of mercury	345.3162	kilograms per square meter
inches of water	0.0735559	inches of mercury
"	0.1868324	centimeters of mercury
"	0.0361275	pounds per square inch
"	5.202360	pounds per square foot
"	25.400051	kilograms per square metre
kilograms	2.20462234	pounds
"	35.273957	ounces
"	1000	grams
kilogram-calories	3.9685	Btu
"	3,087.4	foot-pounds
"	426.85	kilogram-meters
kilogram-meters	7.2329983	foot-pounds
"	9.80665×10^7	ergs
kilograms per cubic meter	0.06242833	pounds per cubic foot
"	0.001	grams per cubic centimeter
kilograms per meter	0.6719702	pounds per foot
kilograms per square meter	0.00142234	pounds per square inch
"	0.2048169	pounds per square foot
"	0.00289590	inches of mercury
"	0.003280833	feet of water
"	0.1	grams per square centimeter
kilometers	3,280.833	feet
"	0.6213700	miles
"	0.539553	nautical miles
kilometers per hour	0.9113426	feet per second
"	0.6213700	miles per hour
"	0.2777	meters per second
"	0.539553	knots
knots	1	nautical miles per hour
"	1.688944	feet per second
"	1.151553	miles per hour
"	1.853249	kilometers per hour

CONVERSION FACTORS

Multiply	By	To Obtain
knots	0.514791	meters per second
liters	1000.027	cubic centimeters
“	61.02503	cubic inches
“	0.035315411	cubic feet
“	0.264178	gallons
“	0.219975	Imperial gallons
meters	39.37	inches
“	3.280833	feet
“	1.093611	yards
meters per second	3.280833	feet per second
“	2.2369317	miles per hour
“	3.6	kilometers per hour
miles	5280	feet
“	1.609347	kilometers
“	0.8683925	nautical miles
miles per hour	1.46666	feet per second
“	0.4470409	meters per second
“	1.609347	kilometers per hour
“	0.8683925	knots
miles per hour squared	2.151111	feet per second squared
ounces	1/16	pounds
“	28.349527	grams
“	437.5	grains
pounds	453.5924277	grams
“	0.45359243	kilograms
“	16	ounces
“	32.174	poundals
pounds per cubic foot	16.018369	kilograms per cubic meter
“	0.016018369	grams per cubic centimeter
pounds per cubic inch	1728	pounds per cubic foot
“	27.6797424	grams per cubic centimeter
pounds per square inch	2.036009	inches of mercury
“	2.306645	feet of water
“	0.0680457	atmospheres
“	703.06687	kilograms per square meter
“	0.07036	kilograms per square centimeter
radians	57.29578	degrees (arc)
radians per second	57.29578	degrees per second
“	0.159155	revolutions per second
“	9.84930	revolutions per minute
revolutions	6.283185	radians
revolutions per minute	0.104720	radians per second
slugs	32.174	pounds
square centimeters	0.1549997	square inch
“	0.00107639	square feet
square feet	929.03412	square centimeters
“	0.092903412	square meters
square inches	645.162581	square millimeters
“	6.4512581	square centimeters
square kilometers	0.3861006	square miles
square meters	10.76386736	square feet
“	1.1959853	square yards
square miles	2.59	square kilometers
square yards	0.8361307	square meters

GLOSSARY OF UNITED STATES—BRITISH AERONAUTICAL TERMS

American	British
Airplane	Aeroplane
Battery, storage	Accumulator or storage battery
Bearing, antifriction	Ball or roller bearing
Can	Tin
Carburetor	Carburettor or carburetter
Clevis	Fork joint, knuckle joint end, or clevis
Club, test	Test fan
Commutator	Inverter or commutator
Cone, split or split wedge	Collet
Cone, union	Union nipple
Control, altitude mixture	Mixture control, automatic mixture control, or altitude control
Duct, air	Interconnecting sleeve or trousers
Engine or power plant	Aero-engine
Engine section (complete)	Power plant or power egg
Filter, air	Air cleaner
Filter, screen or strainer (oil)	Filter
Flaps	Gills
Gall or fret, to	Fret, to
Gasket	Joint, washer, or gasket
Gasoline, gas, or fuel	Petrol or fuel (preferable)
Gauge, fuel, or fuel gauge	Fuel contents gauge or fuel level indicator
Generator	Dynamo
Ground (electrical)	Earth or ground
Hardware	Ironmongery
Kerosene or coal oil	Paraffin, kerosene, or petroleum
Lean	Weak
Left	Port
Muffler	Silencer
Nipple, union	Union
Nut, spanner	Ring nut
Oil, slushing, or slushing compound	Corrosion inhibitor
Pad	Accessory mounting face
Palnut	Lock nut (type of)
Pan, oil	Crankcase sump
Pin, cotter	Split pin
Pin, piston	Gudgeon pin or piston pin
Pin, wrist or knuckle	Wrist pin or anchor pin
Plug or attachment	Plug
Plug, spark	Sparking plug
Post, binding	Terminal
Pressure, manifold	Boost pressure or boost
Prime, to	Prime or dope, to
Propeller	Airscrew (obsolete), propeller
Raw (liquid)	Neat
Ring, exhaust collector, or exhaust manifold	Exhaust ring or exhaust manifold
Ring, lock or snap	Circlip
Rod, link or articulated	Auxiliary connecting rod
Screw, cap	Set screw
Screw, fillister head	Cheese-headed screw
Screw, flat-head	Countersunk-head screw
Screw, round-head	Round-head screw or cupheaded screw
Setscrew	Grub screw
Shield or screen (ignition)	Ignition harness or screening
Socket or plughole	Socket

American	British
Stack	Pipe (single)
Tachometer	Engine speed indicator (E. S. I.), tachometer, revolution indicator, or revolution counter
Test, block	Test after overhaul
Thermocouple	Pyrometer
Valve, check	Non return valve or check valve
Vent	Vent-pipe
Washer, lock	Spring washer
Wire, lock	Safety wire
Wrench	Spanner or wrench
Wrench, box-end, closed spanner wrench, or spanner wrench	Ring spanner
Wrench, socket	Box spanner

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